Northern Link

Phase 2 – Detailed Feasibility Study

Environmental Impact Statement

TECHNICAL REPORT 9A

CONSTRUCTION NOISE & VIBRATION

18 September 2008

Executive Summary

1. Introduction

1.1 Background

Heggies Pty Ltd (Heggies) has been commissioned by the SKM Connell Wagner Joint Venture (JV) to prepare an assessment of the construction noise and vibration aspects associated with the Northern Link project, for inclusion into the Environmental Impact Statement (EIS).

The specific requirements of the Terms of Reference[1] in relation to the construction noise and vibration impacts associated with the project are reproduced below.

- ***Description of Existing Environment***
  - Reviewing available data
  - Identifying representative existing, committed and approved sensitive places
  - Conducting additional baseline noise monitoring
  - Describing existing levels of road traffic noise
- ***Potential Impacts and Mitigation Measures – Construction***
  - Identification and assessment of all noise and vibration sources which may arise from the construction of the project
  - The potential environmental impact of noise and vibration at all potentially sensitive places
  - Assessment should be made of the potential emission of low-frequency noise
  - Proposals to prevent, minimise or mitigate these effects
  - Identification and assessment of significant noise impacts associated with potential spoil haulage routes
  - Identification of mitigation measures to address construction noise and vibration impacts
  - Discussion of a noise and vibration monitoring program to be implemented during the construction period

This assessment is to be inclusive of noise and vibration impacts to or on critical or sensitive places and the Toowong Cemetery, and determine the ground vibration effects on grave sites and equipment within health care facilities.

[1] Queensland Government's Department of State Development and Innovation, *Northern Link Project – Terms of Reference for an Environmental Impact Statement.*

Objectives

The objectives of this report in relation to the project description are to:-

- Address the acoustical requirements detailed in the project's Terms of Reference in relation to the construction phase of the project;
- Evaluate the construction noise and vibration impacts at sensitive locations in terms of planning levels identified in the EPP[Noise] and other Guidelines;
- Define noise and vibration criteria by which construction noise and vibration impacts at sensitive locations may be evaluated;
- Evaluate the extent of resulting impacts and the scope for the reduction of these impacts through reasonable and feasible mitigation strategies; and
- Recommend appropriate mitigation measures.

2. IMPACT ASSESSMENT CRITERIA

Community Values Relating to Noise and Vibration

The Queensland Environmental Protection (Noise) Policy 1997 defines the values to be protected as the qualities of the acoustic environment that are conducive to:

a. The wellbeing of the community or a part of the community, including its social and economic amenity; or

b. The wellbeing of an individual, including the individual's opportunity to have sleep, relaxation and conversation without unreasonable interference from intrusive noise.

Noise Impact Assessment Goals

The Environmental Protection Amendment (No 2) Regulation 1999 (EPAR) requires that a builder or building contractor not to carry out building work on a building site in a way that makes or causes audible noise to be made from the building work:

a. *On a Sunday or public holiday, at any time; or*

b. *On a Saturday or business day, before 6.30 am or after 6.30 pm.*

This project would involve some instances where construction activity would be required to be undertaken on a 24 hour basis and that would likely be audible outside of the regulated construction hours. Accordingly, the project would require approval to operate outside of the regulated hours.

There are no established goals criteria in Queensland for the assessment of impacts associated with long-term construction noise sources, especially at night. It is suggested that assessment goals for long-term construction noise sources should reflect the noise environment that is considered acceptable for normal functioning of adjoining developments (eg residential, healthcare and educational uses).

Thus, the potential impacts of long-term construction noise sources have been assessed by comparison with the following goals:

1. Sleep disturbance goals contained in statutory guidelines and policies.
2. Recommended internal noise levels for various building uses specified in AS/NZS 2107: 2000 Acoustics – Recommended design sound levels and reverberation times for building interiors.
3. Comparison with the existing noise environment.

Sleep Preservation

Both the Brisbane City Council's *Noise Impact Assessment Planning Scheme Policy* (NIAPSP) and the Queensland Environmental Protection Agency's Ecoaccess Guideline *Planning for Noise Control* recommend maximum internal noise levels in sleeping areas to avoid sleep disturbance. The recommended maximum levels from these two policies are summarised in **Table 2**

Table 2 Regulatory Guidelines for Avoidance of Noise-induced Sleep Disturbance

Guideline	Recommended Maximum Internal LAmax	Recommended Maximum Number of Occurrences per Night
BCC NIAPSP[1]		
AS1055.1 Appendix A R1-R3 Categories	45 dBA	"must not regularly exceed"
AS1055.1 Appendix A R4-R6 Categories	50 dBA	"must not regularly exceed"
EPA Ecoaccess	"Approximately 45 dBA"	"no more than 10 to 15"

Note 1: Contained in the NIAPSP Draft Guideline 2001.

The NIAPSP approach to assessing sleep disturbance is preferred as it includes some recognition that sleep disturbance is a function of the background noise level in addition to the level of the intrusive sound.

Acceptable levels of steady or near-steady ("quasi-steady") noise for sleeping environments are recommended in Australian Standard AS2107 *Acoustics – Recommended Noise Levels and Reverberation Times for Building Interiors.*

Vibration Impact Assessment Criteria

Given a sufficiently high vibration level the potential adverse effects of vibration in buildings generated by construction activities are threefold:

- Occupants or users of the building may be inconvenienced or possibly disturbed;
- The building contents may be disturbed or affected; and
- Cosmetic or structural building damage may be induced.

Property Impacts

In terms of the relevant vibration damage criteria, British Standard 7385:Part 2-1993 *Evaluation and Measurement for Vibration in Buildings* is a definitive standard against which the likelihood of cosmetic building damage from ground vibration can be assessed.

BS 7385 sets guide values for building vibration based on the lowest vibration levels above which cosmetic damage has been credibly demonstrated. These levels are judged to give a minimal risk of vibration-induced cosmetic damage, where 'minimal risk' for a named effect is usually taken as a 95% probability of no effect.

An earlier reference than BS 7385, German Standard DIN 4150:Part 3-1986 also provides commonly referenced guidelines for evaluating the effects of vibration on structures.

The Queensland Environmental Protection (Noise) Policy 1997, (EPP (Noise)) defines acceptable vibration limits for blasting with 80% compliance in stating that:

> *"The noise from blasting is reasonable if, measured outside the most exposed part of an affected noise sensitive place*
>
> a. *the air-blast overpressure is not more than 115 dB(Lin Peak) for 4 out of any 5 consecutive blasts; and*
>
> c. *the ground vibration is*
>
>   a. *for vibrations of more than 35 Hz - not more than 25 mm/s ground vibration, peak particle velocity; or*
>
>   b. *for vibrations of not more than 35 Hz - not more than 10 mm/s ground vibration, peak particle velocity."*

Part 6 of the Brisbane City Council Local Law 5 - *Permits and Licences* specifies vibration limits for blasting. The key environmental management requirements of this are:

Provision of formal notification of intention to blast 24 hours in advance.

Performance of pre- and post-construction building condition surveys for all buildings where the anticipated ground vibration level will be 10 mm/s peak particle velocity or greater.

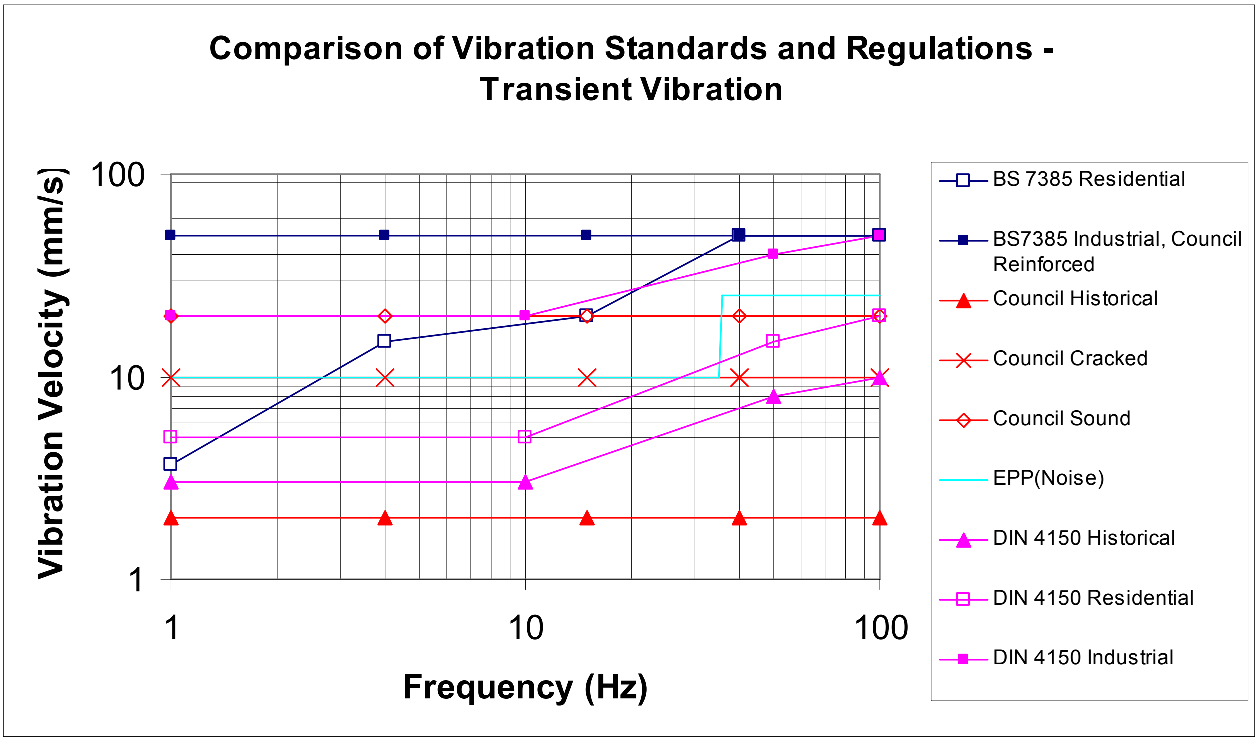
Compliance with the ground vibration limits shown in ***Table* 4.**

- **Table 4 Council Ground Vibration Limits – Part 6 of Local Law 5**

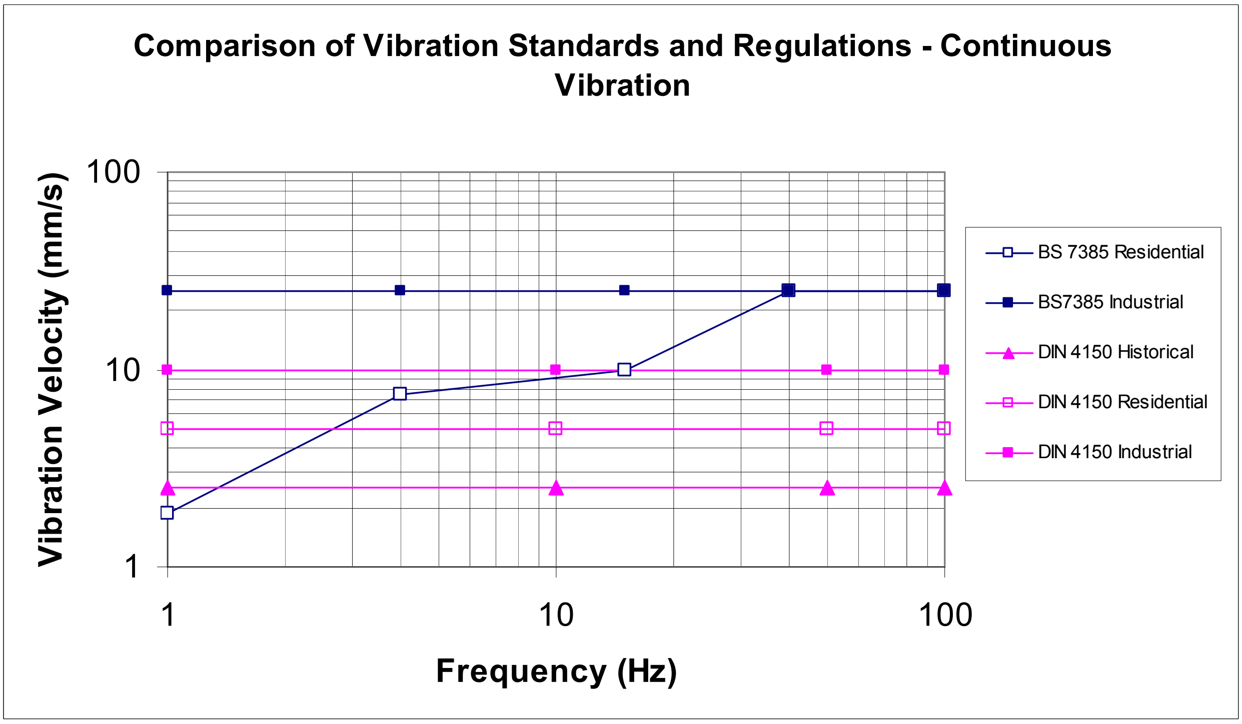
Type of Building or Structure	**Ground Vibration Limit (peak particle velocity)**
Historical buildings, monuments or ruin	2 mm/s
Visibly damaged or cracked buildings or structures	10 mm/s
Structurally sound buildings or structures	20 mm/s
Reinforced concrete or steel buildings or structures	50 mm/s

The vibration guide values and limits expressed in the standards and regulations discussed above are expressed graphically in **Figure 1** for transient or blast vibrations and in **Figure 2** for continuous vibration.

■ **Figure 1 Comparison of Standards and Regulations – Transient Vibration**



■ **Figure 2 Comparison of Standards – Continuous Vibration**



The assessment guide values for transient and continuous vibration in order to ensure a minimal risk of cosmetic damage to residential and other sensitive buildings are presented numerically in **Table 5.**

▪ **Table 5 Vibration Assessment Guide Values – Minimal Risk of Cosmetic Damage**

Vibration Type	Peak Particle Velocity (mm/s)		
	Heritage Listed	Residential	Sensitive Commercial
Transient Vibration (eg blasting)	2	10	10
Continuous Vibration (eg TBM, roadheading, rockhammering)	2	5	5

Building Contents

Over the frequency range typical of vibration in buildings from excavation and construction equipment (approximately 8 Hz to possibly 100 Hz), the threshold for visible movement of susceptible building contents (eg plants, hanging pictures, blinds, etc.) is approximately 0.5 mm/s. Audible rattling of loose objects (eg crockery) generally does not occur until levels of about 1 mm/s are reached.

Potentially vibration-susceptible building contents include sensitive instrumentation, computers and other electronic equipment.

Where particularly sensitive building contents have been identified, it is normal to undertake preliminary tests to establish the threshold of sensitivity before construction works proceed.

Human Comfort

Human tactile perception of vibration, as distinct from human comfort considerations, is summarised in German Standard DIN 4150 Part 2-1975. The degrees of perception for humans are suggested by the continuous vibration level categories given in **Table 7**.

▪ **Table 7 Vibration Levels and Human Perception of Motion**

Approximate Vibration Level	Degree of Perception
0.10 mm/s	Not felt
0.15 mm/s	Threshold of perception
0.35 mm/s	Barely noticeable
1.0 mm/s	Noticeable
2.2 mm/s	Easily noticeable
6 mm/s	Strongly noticeable
14 mm/s	Very strongly noticeable

Note: These approximate vibration levels (in floors of building) are for vibration having a frequency content in the range of 8 Hz to 80 Hz.

Australian Standard AS 2670.2-1990 provides "human comfort" criteria for building use categories, including the following (in order of increasing sensitivity):

- Workshops
- Office
- Residential - day
- Residential - night

- Critical working areas – for example hospital operating theatres, precision laboratories etc.

Table 9 presents the recommended "peak" vibration velocity levels to achieve "low probability of adverse comment" for continuous and transient vibration sources based on human comfort considerations.

- **Table 9 Recommended "Peak" Vibration Velocity Levels for Human Comfort**

Type of Space Occupancy	Time of Day	Peak Vibration Levels in mm/s corresponding to a Low Probability of Reaction			
		Continuous Vibration (16h Day, 8h Night)		Transient Vibration Excitation with several Occurrences per day	
		Vertical	Horizontal	Vertical	Horizontal
Critical working areas	Day or Night	0.14	0.4	0.14	0.4
Residential	Day Night	0.3 to 0.6 0.2	0.8 to 1.5 0.6	4 to 13 0.2 to 3	13 to 36 0.6 to 8.4
Offices	Day or Night	0.6	1.7	8 to 18	24 to 52

As can be seen from the last two columns of **Table 9** situations can exist where vibration magnitudes above those generally corresponding to a low probability of reaction, particularly for temporary disturbances and infrequent and intermittent events such as those associated with blasting, can be tolerated.

Sleep Preservation

It is difficult to define the level of vibration that would disturb sleep at night, as there is not a significant body of research that specifically investigates this issue.

A vibration guide level of 0.5 mm/s (peak) has been estimated. This estimate is based on consideration of vibration levels commonly associated with the on-set of movement and rattling of building contents, vibration guide values based on human perception nominated in AS2670-1990, and the qualitative perception scale for continuous vibration outlined in German Standard DIN 4150 Part 2-1975.

Air-blast

While cracked plaster is the type of damage most frequently monitored in airblast complaints, research has shown that window panes fail before any other structural damage occurs (USBM, RI 8485-1980). The probabilities of damage to windows exposed to a single airblast event are as shown in **Table 11.**

Table 11 Probability of Window Damage from Airblast

Airblast dB Linear	Level kPa	Probability of Damage	Effects and Comments
140	0.2	0.01%	"No damage" - windows rattle
150	0.6	0.5%	Very occasional failure
160	2.0	20%	Substantial failures
180	20.0	95%	Almost all fail

The EPP (Noise) specifies a human comfort requirement of 115 dB (Linear Peak) for airblast.

3. Identification of Special Noise/Vibration Sensitive Buildings

Apart from the residential dwellings that are in the vicinity of the Northern Link connections and route alignment, there is a number of other noise/vibration sensitive locations that have been identified which have been considered in this report when assessing the potential for impacts arising from airborne or regenerated noise and vibration.
They include the following types of facilities:

- Aged care
- Child care
- Place of Worship
- Education
- Heritage
- Commercial

4. Existing Noise Environment

Introduction

The aspects of the tunnel infrastructure that are of particular interest in respect of the existing noise environment are those areas in the vicinity of:-

- Construction sites,
- Ventilation Outlets, and
- Tunnel portals and associated connections.

Noise Monitoring Sites

Noise monitoring sites have been selected to be representative of catchments that may be potentially affected by the Northern Link project.

The details of the selected noise monitoring sites, and their relevance to potential tunnel noise issues is summarised in **Table 5**.

Table 5 Noise Monitoring Locations

Location Number	Monitoring Location	Relevance to Tunnel Noise Issues
1	22 Crag Road, Taringa	Operational (surface traffic)
2	115 Elizabeth Street, Toowong	Construction and operational (surface traffic and/or ventilation station) impacts associated with the western portal
3	6 Wool Street, Toowong	Operational (ventilation station) impacts associated with western portal
4	128 Sylvan Road, Toowong	Operational impacts associated with Frederick Street portal
5	29 Valentine Street, Toowong	Construction and operational (surface traffic) impacts associated with Frederick Street portal
6	69 Frederick Street, Toowong	Construction and operational (road traffic) impacts associated with Frederick Street portal
7	9 Victoria Crescent, Toowong	Construction and operational (road traffic) impacts associated with Frederick Street portal
8	5 Clyde Street, Brisbane City	Operational impacts associated with the eastern portals
9	26 Lower Clifton Terrace, Red Hill	Construction and operational (road traffic and ventilation station) impacts associated with the eastern portals
10	7 Westbury Street, Red Hill	Construction and operational (surface traffic) impacts associated with the Kelvin Grove portal
11	Inner Northern Busway (INB), Normanby Station	Construction and operational (surface traffic) impacts associated with the Inner City Bypass (ICB) portal
12	43 Normanby Terrace, Kelvin Grove	Construction and operational (surface traffic) impacts associated with the ICB portal
13	9 Horrocks Street, Toowong	Construction and operational (surface traffic) impacts associated with the western portal
14	QUT, Kelvin Grove Campus	Operational (ventilation station) impacts associated with the eastern portal

Noise monitoring was conducted generally in accordance with Australian Standard AS1055-1997 *Acoustics – Description and Measurement of Environmental Noise* and the Queensland Environmental Protection Agency's *Noise Measurement Manual* 2000. The noise environment in the study corridor is typical of many inner urban areas, in that it is largely determined by road traffic noise. However, at some locations rail noise and/or mechanical plant noise are other significant sources.

The dominant audible sounds at each location are summarised in **Table 7**.

Table 7 Description of Existing Noise Sources

Location Number	Monitoring Location	Dominant Daytime & Evening Noise Sources	Dominant Noise Sources Late at Night
1	22 Crag Road, Taringa	Western Freeway traffic	Western Freeway traffic
2	115 Elizabeth Street, Toowong	Western Freeway traffic	Western Freeway traffic
3	6 Wool Street, Toowong	Western Freeway road traffic and mechanical plant and equipment noise from bus depot	Western Freeway and occasional Miskin Street traffic
4	128 Sylvan Road, Toowong	Milton Road and Sylvan Road traffic	Milton Road and Sylvan Road traffic
5	29 Valentine Street, Toowong	Milton Road and Frederick Street traffic	Milton Road and Frederick Street traffic
6	69 Frederick Street, Toowong	Frederick Street traffic and transformer noise	Frederick Street traffic and transformer noise
7	9 Victoria Crescent, Toowong	Frederick Street traffic	Frederick Street traffic and transformer noise
8	5 Clyde Street, Brisbane City	Musgrave Road and Hale Street traffic	Musgrave Road and Hale Street traffic
9	26 Lower Clifton Terrace, Red Hill	Kelvin Grove Rd and ICB traffic	Kelvin Grove Rd and ICB traffic
10	7 Westbury Street, Red Hill	Kelvin Grove Rd traffic	Kelvin Grove Rd traffic
11	Inner Northern Busway (INB), Normanby Station	Ithaca Street, ICB and INB road traffic and rail traffic (including freight)	Ithaca Street and ICB road traffic and rail traffic (including freight)
12	43 Normanby Terrace, Kelvin Grove	ICB road traffic and rail traffic (including freight)	ICB road traffic and rail traffic (including freight)
13	9 Horrocks Street, Toowong	Mt Coot-tha Rd and Western Freeway traffic	Western Freeway traffic
14	QUT, Kelvin Grove Campus	Victoria Park Road and ICB traffic	ICB traffic

Results of the noise logger measurements were then analysed in terms of:

- Background (L_A90) levels
- L_{Aeq} (1hr) – day, evening and night
- Lmax – Average – day, evening and night

Vibration Measurements

Vibration measurements were carried out at various locations to determine existing vibration levels. The summarised results of the vibration measurements are documented in **Table 13**.

Table 13 Summarised Vibration Measurements

Monitoring Location	Date - Time	Peak Component Particle Velocity (mm/s)	Dominant Frequency (Hz)
1 – Normanby Terrace (behind #43 near cycle path)	29/11/07 – 8:36	0.03	<1.0
2 – Normanby Terrace (along #9)	29/11/07 – 9:07	0.04	<1.0
3 – Normanby Busway Station	29/11/07 – 9:31	0.09	1.2
4 – Kelvin Grove Rd side of 25 Musgrave Rd	29/11/07 – 9:58	0.26	20
5 – Along 25 Upper Clifton Tce	29/11/07 – 10:31	0.09	<1.0
6 – Westbury St Kelvin Grove Rd intersection	29/11/07 – 10:56	0.11	N/A
7 – Toowong Cemetery (south-west corner)	29/11/07 – 11:48	0.05	<1.0
8 – Thorpe St Frederick St intersection	29/11/07 – 12:31	0.07	N/A
9 – In front of 5 Thorpe St	29/11/07 – 12:53	0.02	<1.0

These measurements show that at the majority of the monitoring locations the existing vibration levels are below the threshold level of human perception (~ 0.15 mm/s).

5. Reference Noise and Vibration Data

A summary of these plant items, their function, likely location of use on the project and indicative sound power level are summarised in **Table 19.**

It is proposed to enclose night-time noise sources within large enclosures in noise-sensitive areas to allow spoil accumulation on a 24 hour basis.

Table 19 Source Sound Power Level Estimates for Mechanical Plant

Description of Plant	Sound Power Level (LAmax dBA)	Plant Function	Possible Locations of Use
25t Articulated off-road Dump Truck	114	Underground spoil haulage from tunnel face	All areas of tunnel excavation
On-road Truck and Dog	103	Off-site spoil transport	All earthworks areas
20t, 100 kW Excavator	112	Spoil loading	Initial excavations of cut and cover areas and launch pits
35t, 200 kW Excavator	114	Surface excavation; rubble removal	Initial excavations of cut and cover areas and launch pits
200 kW Grader	116	Road grading	All surface connections
25t, 200 kW Front-end Loader	116	Spoil loading	All worksite enclosures
38t, 250 kW Dozer	118	Ripping and clearing	Initial excavations of cut and cover areas
600 kW Electric Conveyor Drive	106	Transport of spoil along tunnel to surface	Transport of spoil between EPB and spoil enclosures
Spoil Conveyor (Low Noise Idlers)	83 per metre	Surface transport of spoil from worksite	Western Connection to Mt Coot-tha quarry
Pneumatic Rock Drill	120	Pre-drilling for rock-bolting, drilling for explosives	All excavations in loose rock, all drill and blast operations
Large Air Compressor	103	Supply to rock drill	All drilling operations
Hydraulic Rockbreaker	120	Loosening rocky ground, trimming rock faces	All excavations in loose rock and all drill
20t Mobile Crane	105	Enclosure erection, loading/unloading	All worksites
Pile Boring Rig	118	Excavation for poured concrete piles	Edge of excavations in loose material, retaining walls and launch pits
24t Concrete Truck	112	Concrete delivery	All foundations, pouring of bored piles and shotcreting
Concrete Pump	107	Concrete delivery	All foundations, pouring of bored piles and shotcreting
Asphalt Paver	114	Road surfacing	All surface connections
Roller	104	Compacting and surfacing	All surface connections
100t Hydraulic Crane	110	Heavy lifting of elevated structure components	All surface connections
Water Truck	105	Dust suppression	Northern and Southern
Compressor 285 L/s	100	Power pneumatic tools	All worksites
Semi trailer	114	Delivery of construction equipment	All worksites
Bobcat	112	Spoil mucking	All worksites

Transmission-loss spectra for examples of possible enclosure construction materials are detailed in **Table 21**.

Table 21 Indicative Transmission Loss Spectra for Representative Enclosure Constructions

Material Description	Transmission Loss in Octave Bands (dB)							
	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
1 - Low Performance Option 0.62 mm metal decking	3	8	14	20	23	26	27	35
2 - Medium Performance Option 0.62 mm metal decking lined with 50 mm fibreglass[2]	5 (est)	10	15	22	32	37	43	43
3 - High performance Option 0.62 mm metal decking, 110 mm airspace, 50 mm fibreglass blanket in airspace, internal lining of 18 kg/m^2 porous-faced fibre-board[3]	15 (est)	20	29	43	46	57	63	63

Substantial improvements in the effectiveness of an acoustic enclosure can be achieved by adding an acoustically absorptive internal lining. A further substantial improvement can be achieved by effectively creating a double layer construction for walls and ceiling elements.

The effectiveness of noise barriers typically ranges from 5 dBA if line-of-sight between the noise source and receiver location is just obscured, up to around 15 dBA where the barrier provides optimal blocking of the sound transmission path.

The analysis of potential construction noise impacts in residential buildings is based on the assumption that the noise level difference outside a dwelling to inside a habitable room is a nominal 10 dBA for older type dwellings that rely predominantly on natural ventilation through windows, and 20 dBA for modern residential apartments with close-fitting sliding windows that would normally be equipped with air conditioning.

Vibration

Drill and Blast

Indicative blast vibration levels associated with tunnelling have been sourced from measurements carried out during the trial blasting for Brisbane Rail Tunnel Duplication and ICI Explosives Blasting Guide.

Table 26 shows indicative permissible blast sizes that could result in a ground vibration velocity level of 10 mm/s PPV. This level would relate to residential dwellings and other buildings not containing highly sensitive equipment.

■ **Table 26 Indicative Permissible Maximum Instantaneous Charge (MIC) to achieve 10 mm/s PPV Near Residential Dwellings and other Buildings – Conventional Blasting**

Data Source	Indicative Permissible Charge weight (kg) Versus Distance					
	Exceedance	5 m	10 m	20 m	30 m	40 m
General ICI Tunnelling formula	20%	0.15	0.6	2.3	5.3	9.4
QR Rail Tunnel trial blasts	20%	0.04	0.16	0.65	1.4	2.6

Tunnel Boring Machines (TBMs)

The proposed TBMs are approximately 12 m in diameter.

Likely ground vibration levels for the Northern Link TBMs are shown in **Table 27.**

Roadheaders and Rockbreaking

The typical maximum levels of ground vibration from heavy roadheading and rockbreaking operations are also listed in **Table 27.**

From **Table 27** it can be seen that vibration levels associated with road headers are very low in comparison to other excavation methods.

■ **Table 27 Indicative Maximum Ground Vibration Levels for Mechanical Tunnel Excavation Methods**

Operation	Peak Vibration Levels (mm/s) Versus Distance					
	5 m	10 m	20 m	30 m	40 m	50 m
12 m hard rock TBM	35	10	3	1.5	0.8	0.5
Heavy Rockbreaking	4.5	1.3	0.4	0.2	0.14	0.1
Heavy Roadheading	0.5	0.13	0.04	0.02	0.01	0.01
Blasting - ICI tunnelling formula						
5 kg Maximum Instantaneous Charge	168	55	18	10	6	4
1 kg Maximum Instantaneous Charge	46	15	5	2.6	1.7	1.2
0.2 kg Maximum Instantaneous Charge	13	4.2	1.4	0.7	0.5	0.3

Regenerated Noise

Regenerated noise refers to noise that is first transmitted to the ground by machinery as vibration which then travels to a sensitive location (such as a house) through the ground and foundations, where the walls, floor and ceiling then radiate this vibration as audible noise.

An indicative summary of regenerated noise levels anticipated from mechanical tunnel excavation methods is presented in **Table 28** based on a -30 x $\log_{10}$(distance) relationship between distance and regenerated noise level.

■ **Table 28 Indicative Regenerated Noise Levels for Mechanical Tunnel Excavation Methods**

Operation	Regenerated Noise Levels (dBA) Versus Distance					
	5 m	10 m	20 m	30 m	40 m	50 m
12 m hard rock TBM (based on Dublin Port Tunnel estimate of 55 dBA at 23 m, and Wilkinson Murray data for 7.2m TBM in sandstone, factored up for size, assuming vibration velocity is proportional to TBM face area)	69 - 75	60 - 66	51 - 57	45 - 51	42 - 48	39 - 45
Roadheading (Wilkinson Murray 38dBA @ 20m)	56-62	47-53	38-44	32-38	29-35	26-32
Rockbreaking (RHA 60 dBA @ 10m)	69-75	60-66	51-57	47-53	42-48	39-45
Rockdrilling (RHA 38dBA @ 23m)	58-64	49-54	40-46	36-42	31-37	29-35

6. Assessment of Work Sites

At this stage of the project, there has been no detailed assessment of the construction methodology however, it is still possible to provide a good estimate of the noise emissions based on reference sound power levels for typical items of plant and the anticipated location of plant at each worksite.

The noise emissions from each worksite have been assessed for three scenarios:- site preparation, daytime tunnelling and night-time tunnelling.

Western Connection Worksite (WS1)

The primary noise-generating activities anticipated during the preparation and operation of the western connection worksite (WS1) are summarised in **Table 29**.

■ **Table 29 Western Connection Worksite Surface Works Noise Sources**

Construction Phase and Approx. Duration	Enclosed/Underground Day and Night-time Noise Sources	Additional Daytime Noise Sources
Site Establishment (2 weeks)	Nil	Delivery trucks, excavators, hydraulic rockbreakers, bulldozers, dump trucks, manual trades, compressors, generators
Enclosures Construction (8 weeks)	Nil	Mobile cranes, concrete trucks, concrete pump, delivery trucks, manual trades, excavator, structural steelwork
Works within Enclosure (14 months)	Removal of spoil, supply of temporary support material, ventilation plant, concrete lining of tunnel	Removal of spoil and delivery of materials

Site Preparation

The following conclusions regarding noise impacts associated with site preparation at the western connection worksite (WS1) are drawn from the assessment.

Residents South of Wool Street

- At the closest residences on the southern side of Wool Street, the highest noise levels arise due to the operation of the rockbreaker and the dozer. Based on "typical" emissions, a marginal exceedance of 3 dBA above the external noise goal is predicted whilst the rockbreaker is in use. Given the limited duration of this particular component of the work it is not likely to result in a significant impact.
- The noise from other plant items will comply with the external design goal.

Residents North of Mt Coot-tha Road

- Site preparation works are predicted to be below the noise goal for the closest residences north of Mt Coot-tha Road.

Daytime Tunnelling

The following conclusions regarding noise impacts associated with daytime tunnelling works at the western connection are drawn from the assessment.

Residents South of Wool Street and North of Mt Coot-tha Road

The noise from the plant items are not expected to exceed the design goal at any residence south of Wool Street or north of Mt Coot-tha Road.

Night-time Tunnelling

The following conclusions regarding noise impacts associated with night-time tunnelling works at the western connection are drawn from the assessment.

Residents South of Wool Street and North of Mt Coot-tha Road

- The noise from plant items operating during the night-time period at WS1 is not expected to exceed the LAeq(15minutes) or LAmax design goal with the exception of the spoil conveyor which is predicted to marginally exceed the LAeq(15minutes) noise goal. As a result, no significant acoustical impacts would be expected.
- Apart from the detailed design of the enclosure (dedicated structure or enclosed cut and cover), the provision of additional noise mitigation should not be considered for residents at this location.

6.1.1 Noise Mitigation

The following noise control measures are recommended for noise mitigation at the western connection worksite:

- Provide advance notification to residents.
- Minimise the use of particularly noisy activities such as rockbreaking.
- Ensure the construction of a 'low' performance acoustic enclosure over the portal and stockpile or acoustic door entry to completed cut and cover structure.
- The movement of trucks within the worksite should be designed to limit (as much as possible) the need for reversing and therefore reversing alarms.

- Noise monitoring at the commencement of and periodically during noise intensive activities.

Vibration Impacts

Due to the separation distances between the majority of the earthworks on the worksite and the cemetery significant vibration impacts are not anticipated from site preparation and surface activities.

Toowong Connection Worksite (WS2)

The primary noise-generating activities anticipated during the preparation and operation of the Toowong connection worksite is summarised in **Table 33**.

Table 33 Toowong Connection Worksite Noise Sources

Construction Phase and Approx. Duration	Enclosed/Underground Day and Night-time Noise Sources	Additional Daytime Noise Sources
Removal of Buildings (2 weeks)	Nil	Excavators, bulldozers, dump trucks, manual trades
Establishment of Site and Enclosure Construction (8 weeks)	Nil	Mobile cranes, concrete trucks, concrete pump, delivery trucks, manual trades, excavator, structural steelwork
Roadheader Tunnelling (25 months)	Dump truck removal of roadheader spoil, supply of temporary support materials, ventilation, supply of concrete for tunnel lining	Removal of spoil and delivery of materials to inside enclosure

The following conclusions regarding noise impacts associated with site preparation at the Toowong connection worksite (WS2) are drawn from the assessment.

- The residents in Valentine Street are located as close as 10 m from the worksite
- A large number of plant items anticipated to be used at the site during initial works will likely exceed the external design goal during normal operation. Exceedances of this nature are common when construction works occur in close proximity to receivers.
- It is important that the use of significant noise generating plant be minimised insofar as possible and that nearby residents are notified of the works in advance.

Milton Road Residences

- Significant exceedances (up to 23 dBA) of the daytime noise goals are also predicted for residences along Milton Road.
- For the majority of the short duration construction works required for site preparation, construction noise levels at Milton Road residences will likely be similar in the level or below existing road traffic noise levels from Milton Road.

Daytime Tunnelling

The following conclusions regarding noise impacts associated with daytime tunnelling works are drawn from the assessment.

Valentine Street Residences

- Due to the close proximity to the tunnel portal and worksite, Valentine Street residences will experience significant construction noise impacts associated with daytime tunnelling activities. Major impacts are associated with heavy vehicles such as concrete and spoil trucks moving on the site.
- As the tunnelling stage of the Toowong connection is anticipated to occur for over two years, consideration of further noise mitigation should be undertaken for this site.
- Further mitigation measures may include:
    - Installation of a temporary noise barrier along the eastern side of the tunnel off ramp adjacent to the Valentine Street cul de sac to reduce heavy vehicle noise near the tunnel portal. The temporary barrier would need to be a minimum of 5 m in height as the adjacent buildings are double storeys. As an alternative, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.
    - Construction of a high performance acoustic enclosure over the portal with indicative acoustic performance.

Milton Road Residences

- Exceedances of the daytime noise design goal are likely to occur for Milton Road residences during periods associated with spoil removal and concrete deliveries to site. Noise levels from these activities are predicted to be below existing road traffic noise levels along Milton Road and therefore are unlikely to result in a significant impact.

Night-time Tunnelling

The following conclusions regarding noise impacts associated with night-time tunnelling works are drawn from the assessment.

Valentine Street Residences

- Due to the close proximity to the tunnel portal and worksite, the nearest Valentine Street residences will experience significant construction noise levels associated with night-time tunnelling activities. A high performance enclosure would be required at this location to reduce the extent of the likely impact. Night-time noise levels are still predicted to be up to 6 dBA above the recommended goals with a high performance enclosure. This would generally be described as a “noticeable” exceedance. However, when machinery is located further within the tunnel, noise levels will decrease.

Milton Road Residences

- As night-time construction works will occur within the acoustic enclosure at the Toowong worksite, received noise levels from spoil stockpiling works will be below the L_{Amax} and LAeq(15minutes) noise goal.

Noise Mitigation

As for WS1 worksite except for:

- Where feasible install (temporary) noise barriers to reduce construction noise.
- As an alternative, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.
- Construction of a high performance acoustic enclosure over the portal and stockpile area.

Vibration Impacts

The bulk of the vibration intensive works will take place beyond 20 m from sensitive receivers and is therefore unlikely to exceed the vibration criteria. However it is normal environmental monitoring practice to monitor vibration on structures from vibratory rolling that occurs within a nominal distance of 25 m. This may be relevant for Valentine Street buildings.

Kelvin Grove Connection Worksites (WS3)

The primary noise-generating activities anticipated during the preparation and operation of the Kelvin Grove connection worksites (WS3) are summarised in **Table 37**.

Table 37 Kelvin Grove Connection Worksites (WS3) Noise Sources

Construction Phase and Approx. Duration	Enclosed/Underground Day and Night-time Noise Sources	Additional Daytime Noise Sources
Removal of Buildings (2 weeks)	Nil	Excavators, hydraulic rockbreakers, bulldozers, dump trucks, manual trades, compressors, generators
Establishment of Site and Enclosure Construction x2 (8 weeks for both enclosures)	Nil	Mobile cranes, concrete trucks, concrete pump, delivery trucks, manual trades, excavator, structural steelwork
Roadheader Tunnelling (32 months – Kelvin Grove Rd portal, 15 months – Lower Clifton Tce portal)	Dump truck removal of roadheader spoil, supply of temporary support materials, ventilation, supply of concrete for tunnel lining	Removal of spoil and delivery of materials to inside enclosure

Noise Impacts

Site Preparation

The following conclusions regarding noise impacts associated with site preparation at the Kelvin Grove connection worksite (WS3) are drawn from the assessment.

Residents West of Lower Clifton Terrace

- These residents are located approximately 20 m from the tunnel worksite and essentially look down onto the site as the ground rises upwards towards Red Hill.
- At this location the highest noise levels arise due to the rockbreaker. Based on the sound power level for the rock-breaker exceedances of up to 23 dBA are predicted, whilst it is in use. Although existing ambient noise levels are relatively high in this area, predicted construction noise levels would be clearly discernible within dwellings and likely to result in acoustic impacts (eg interference with passive listening, resting, conversation and watching TV).

- Noise mitigation strategies at this site should focus on the use of quietest available plant and construction techniques to establish the site and where possible expediting the early works to allow construction of the acoustic enclosure which will remain in place until tunnelling is complete.

Upper Clifton Terrace and Westbury Street Residences

- These residents are located adjacent to the identified worksite areas including the Kelvin Grove connection portals.
- The close proximity to the works will lead to significant noise impacts. Noise levels of this magnitude would be audible within dwellings and likely to result in acoustic impacts.
- The relatively small work area should ensure that the site preparation works are of short duration. Nonetheless the extent of the likely impacts requires consideration of all practicable noise mitigation measures so as to maintain a reasonable noise environment.

Kelvin Grove Urban Village / QUT

- Two noise sensitive sites within the this area have been identified:
  - QUT's existing Film and TV Studio – located on the eastern side of QUT and therefore a considerable distance away from the worksite – no construction noise issues are anticipated at this facility
  - QUT's proposed Recording Studio – located in the south western corner of the Kelvin Grove Urban Village – this site is somewhat closer to the worksite but still on the opposite side of Kelvin Grove Rd. No design plans were available at the time of the EIS so it is recommended that a separate specific investigation of construction noise (and vibration) levels be undertaken once plans are available.

Daytime Tunnelling

The following conclusions regarding noise impacts associated with daytime tunnelling works are drawn from the assessment.

Residents West of Lower Clifton Terrace

- At this location the highest noise levels arise due to the arrival and departure of heavy construction vehicles. It should be noted that this part of the assessment considers construction vehicles on site only whereas impacts associated with vehicles movements on public roads are addressed separately.
- Due to the confined worksites at this location, heavy vehicle movements on site would be kept to a minimum. The majority of construction vehicles accessing the site would be truck and dog spoil removal which represent a 6 dBA exceedance of the noise goal.
- As the tunnelling phase of the project will occur for over years, noise mitigation strategies should focus on the use of quietest available plant and construction techniques such as careful design of site access points and vehicle paths to maximise distance to noise sensitive receivers and make use of acoustic enclosures and site buildings to act as screens.

Upper Clifton Terrace and Westbury Street Residences

- Significant acoustic impacts are predicted for residences on Upper Clifton Terrace and Westbury Street.
- On the basis of existing (Year 2007) vehicle movements along Kelvin Grove Road (27,760 southbound and 22,210 northbound – 18 Hour component of AADT) and the predicted maximum vehicle numbers to site (75 to site per day), it is likely that surrounding receivers will associate Northern Link construction vehicles as part of the normal road network particularly since the worksites are immediately adjacent to Kelvin Grove Road.

Night-Time Tunnelling

The following conclusions regarding noise impacts associated with night-time tunnelling works are drawn from the assessment.

Lower Clifton Terrace, Upper Clifton Terrace and Westbury Street Residences

- Due to the close proximity of the surrounding residential receivers to the worksite, a high performance enclosure would be required to significantly reduce the extent of the noise impact, however may still lead to small exceedances (up to 4 dBA) of the night-time noise goal for Upper Clifton Terrace residences.

Noise Mitigation

The following noise control measures are recommended for noise mitigation at the Kelvin Grove connection worksites (WS3) similar noise mitigation measures are recommended for WS3 as they were for WS2 (including a “high performance’ enclosure):

- Advance notification of the time, type and duration of demolition and initial earthworks.
- Minimise the duration of initial noise intensive site works such as rockbreaking.
- Use of quietest available plant and construction techniques for works occurring in the open environment
- Construction of a high performance acoustic enclosure over the portal
- Careful design of the site layout to provide shielding for residences from construction noise. The acoustic enclosure and other site buildings may provide some screening if located between residences and construction plant, particularly for spoil vehicles whilst on site.
- The movement of trucks within the worksite should be designed to limit (as much as possible) the need for reversing and therefore reversing alarms. Where issues with reversing alarms occur, consideration should be given to the use of broadband “buzzer” reversing alarms and/or alarms which actively vary their volume according to the ambient noise levels during activation - rather than constant volume (tonal) “beeping” alarms.
- Design of continuously operating ventilation plant and any other plant that operates at night to meet ‘reasonable’ night-time noise objectives
- Noise monitoring at the commencement of and periodically during noise intensive activities.

Vibration Impacts

The bulk of the vibration intensive works will take place beyond 20 m from sensitive receivers and is therefore unlikely to exceed the vibration criteria. However it is normal environmental monitoring practice to monitor vibration on structures from vibratory rolling that occurs within a nominal distance of 25 m.

Four vibration sensitive sites within the Kelvin Grove Urban Village and QUT have been identified:

- QUT's existing Film and TV Studio - no construction vibration (or regenerated noise) issues are anticipated at this facility
- QUT's proposed Recording Studio – No design plans were available at the time of the EIS so it is recommended that a separate specific investigation of construction vibration (or regenerated noise) levels be undertaken once plans are available.
- Red Cross Processing Facility – At the time of the EIS, some preliminary "measurement" specifications had been received from the Red Cross but no "limit/criterion" specification was available. Therefore, an assessment of construction vibration is recommended to be undertaken at a later stage when further information is available.
- QUT's Institute of Health and Biomedical Innovation – No information in relation to the specific vibration sensitive equipment within this facility had been supplied by QUT at the time of the EIS so it is recommended that a separate specific investigation of construction vibration levels be undertaken if specific items of equipment are identified as vibration sensitive.

7. Surface Construction of Roadways

Western Freeway Connection

The primary noise-generating activities anticipated during the construction of the western surface connection roads, interfacing with the Western Freeway, are summarised in **Table 41**.

Table 41 Western Surface Road Connections - Construction Noise Sources

Construction Phase (and Approx Duration)	Night-time Noise Sources	Additional Daytime Noise Sources
Earthworks (4 months)	Nil	Excavators bulldozers, graders, loaders, bobcats, compaction equipment, dump trucks, water trucks, manual trades
Cut and Cover Construction (9 months)	Nil	Bored piling rig, hydraulic rockbreakers, rock ripping equipment, pneumatic jack hammer, excavators, shotcrete equipment, rock bolting equipment, compressors, cranes, concrete pump
Transition Structure Construction (12 months)	Nil	Bored piling rig, hydraulic rockbreakers, rock ripping equipment, pneumatic jack hammer, excavators, shotcrete equipment, rock bolting equipment, compressors, cranes, concrete pump
New Road Construction and Existing Road Re-surfacing (4 months)	As for daytime but limited to areas of interface with existing Western Freeway road infrastructure	Delivery trucks, paving machine, compaction equipment, line marking

Night-time Western Freeway Road Works

The following conclusions regarding noise impacts associated with night-time surface road works at the western connection are drawn from the assessment.

Residents South of Wool Street

- At the closest residences to the south of Wool Street, the highest noise levels arise due to the operation of the asphalt paver and delivery truck. Based on "typical" emissions, an exceedance of 4 dBA above the external L_{Amax} noise goal is predicted whilst road resurfacing works are taking place. The predicted construction noise levels are based on a worst case scenario when the plant are operating at the closest point to the receiver and do not take into consideration effects from topography. Construction noise levels may be at least 5 dBA lower if line of sight is broken due to topography or other buildings which may be the case for some Wool Street receivers.
- The noise from other plant items will comply with the external noise design goals.

Residents North of Mt Coot-tha Road

- Night-time Northern Link road construction works are predicted be below the noise design goals at the closest residences north of Mt Coot-tha Road.

Daytime Surface Connection Works

The following conclusions regarding noise impacts associated with daytime surface road works at the western connection are drawn from the assessment.

Residents South of Wool Street

- At the closest residences to the south of Wool Street, the highest noise levels arise due to the operation of the rockbreaker and rock drill. These items of plant are typically used on an intermittent basis and will likely be used below existing ground level (ie within the cut) therefore creating a barrier effect on noise emissions from the site. This is particularly the case during the latter stages of the cut and cover and transition construction works.
- Other plant items such as bored piling rigs and excavators will be required to operate over many months and may have the potential to result in an acoustic impact (ie audible inside dwellings) for residences to the south of the Western Freeway.
- It is recommended that noise monitoring be carried out at the commencement of bored piling works to confirm received construction noise levels to identify if further noise mitigation is required such as localised acoustic screens.

Residents North of Mt Coot-tha Road

- At the closest residences north of Mt Coot-tha Road, surface road construction works are predicted to comply with the nominated noise goal.

Noise Mitigation

The following noise control measures are recommended for noise mitigation during surface road construction:

- Advance notification to the residents
- Selection of quietest available construction plant and techniques
- Location of plant items to maximise distance to noise sensitive receivers
- Attended noise measurements at the commencement of long-term noise intensive construction works
- Where feasible, erect temporary acoustic screens
- Noise monitoring at the commencement of and periodically during noise intensive activities

Vibration Impacts

The majority of these works will take place far enough away from vibration sensitive receivers to avoid any impact.

Rockbreaking may be required at the TBM launch pits located adjacent to the Toowong Cemetery. If the works are required to take place within 10 m of grave sites then vibration monitoring should be carried out to ensure vibration levels do not exceed the 2 mm/s goal listed in **Table** .

Toowong Connection

The primary noise-generating activities anticipated during the construction of the Toowong surface connections are summarised in **Table 44**.

- **Table 44 Toowong Surface Connections - Construction Noise Sources**

Construction Phase and Approx. Duration	Night-time Noise Sources	Daytime Noise Sources
Removal of buildings (2 months)	Nil	Excavators, hydraulic breakers, bulldozers, dump trucks, manual trades, compressors, generators
Earthworks (8 months)	Nil	Excavators, bulldozers, graders, loaders, bobcats, compaction equipment, dump trucks, water trucks, manual trades
Cut and cover Construction (3 months)	Nil	Bored piling rig, excavators, rockbreakers, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Elevated structures (4 and 8 months)	As for daytime but limited to areas where works are required on or over Milton Road.	Bored piling rig, excavators, steel fixing, compressors, crane, concrete pump
Road surfacing for first stage traffic diversion (7 months)	As for daytime but limited to areas of interface with existing road infrastructure.	Delivery trucks, paving machine, compaction equipment, line marking
Road surfacing for final traffic arrangement (5 months)	As for daytime but limited to areas of interface with existing road infrastructure.	Delivery trucks, paving machine, compaction equipment, line marking

Night-time Construction of Toowong Connection Elevated Structures

The following conclusions regarding noise impacts associated with night-time surface road works at Toowong are drawn from the assessment.

Residences on Valentine Street and South of Milton Road

- The noise levels for residences surrounding the Northern Link elevated structures construction would likely be found intrusive (up to 22 dBA above the $L_{Aeq(15minutes)}$ noise goals). Additionally, exceedances of 20 dBA above the L_{Amax} noise goal are predicted. This level of intrusion would interfere with normal indoor living (eg interference with passive listening, resting and conversation) and could cause sleep disturbance. Consequently, it is necessary that all reasonable and feasible noise mitigation be examined so as to maintain a reasonable noise environment at these residences during the construction works.
- It should be noted that whilst the road structure under construction is elevated above Milton Road, the majority of the noise intensive plant required to complete the works will be positioned on or adjacent to Milton Road. This provides an opportunity for construction plant to be located behind approach ramps or safety barriers/hoarding etc, to both maximise distance to receivers as well as create a barrier effect and reduce the likely impact.
- If modification to the process is ineffective, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.

Daytime Surface Connection Works

The following conclusions regarding noise impacts associated with daytime surface road works at Toowong are drawn from the assessment.

Residences on Valentine Street and South of Milton Road

- The noise levels for residences surrounding the Northern Link earthworks, elevated structures and cut and cover construction would likely be found intrusive (up to 29 dBA above the LAeq(15minutes) noise goals). This level of intrusion would interfere with normal indoor living (eg interference with passive listening, resting and conversation) and could cause sleep disturbance. Consequently, it is necessary that all reasonable and feasible noise mitigation be examined so as to maintain a reasonable noise environment at these residences during the construction works. The temporary noise barrier around the Toowong cut and cover site would also provide a reduction in construction noise levels during the cut and cover works.

Noise Mitigation

Noise mitigation measures similar to the Western Connection are recommended.

Vibration Impacts

Some of this work will take place in close proximity (less than 25 m) from vibration sensitive receivers presenting potential impacts. Therefore it is important that nearby receivers are notified in advance of the vibration intensive works and that monitoring be carried out at the commencement of the works.

Kelvin Grove Road Connection

The primary noise-generating activities anticipated during the construction of the Kelvin Grove Road surface connections are summarised in **Table 47**.

- **Table 47 Kelvin Grove Road Surface Connections - Construction Noise Sources**

Construction Phase and Approx Duration	Night-time Noise Sources	Daytime Noise Sources
Removal of buildings (1 month)	Nil	Excavators, hydraulic breakers, bulldozers, dump trucks, manual trades, compressors, generators
Earthworks (2 months)	Nil	Excavators, hydraulic breakers, bulldozers, dump trucks, manual trades, compressors, generators
Cut and cover construction (15 months)	Bored piling. excavators, steel fixing, lifting precast items, concreting equipment and road surfacing	Bored piling rig, excavators, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Road surfacing for first stage traffic diversion (7 months)	As for daytime but limited to areas of interface with existing Sandgate Rd	Bored piling rig, excavators, steel fixing, compressors, crane, concrete pump
Road surfacing for final traffic arrangement (7 months)	As for daytime but limited to areas of interface with existing road infrastructure (Sandgate Rd and East West Arterial)	Delivery trucks, paving machine, compaction equipment, line marking

Noise Impacts

Daytime Construction of Kelvin Grove Road Cut and Cover Structures

The following conclusions regarding noise impacts associated with daytime surface road works at Toowong are drawn from the assessment.

Lower Clifton Terrace, Upper Clifton Terrace and Westbury Street Residences

- For residential locations west of Kelvin Grove Road, the predicted daytime LAeq(15minutes) noise levels from the cut and cover construction works are up to 21 dBA higher than the desired noise goals. This would be found to be intrusive and this level of intrusion would result in an acoustic impact on the residences.

Noise Mitigation

The following noise control measures are recommended for mitigation of Northern Link construction noise around surface road works for the Kelvin Grove connections.

- Advance notification to the residents
- Where possible, select construction processes and plant to minimise construction noise
- If required, assist owners of properties nearest the construction site to temporarily upgrade the acoustical insulation and ventilation of rooms

- Noise monitoring at the commencement of and periodically during noise intensive activities
- Early construction of the operational noise barriers west of Kelvin Grove Road

Vibration Impacts

The bulk of the vibration intensive works, will take place beyond 20 m from sensitive receivers and is therefore unlikely to exceed the vibration goals.

ICB Connection

The primary noise-generating activities anticipated during the construction of the ICB connection is summarised in **Table 49**.

Table 49 ICB Surface Connection - Construction Noise Sources

Construction Phase and Approx Duration	Night-time Noise Sources	Daytime Noise Sources
Cut and cover construction (19 months)	Bored piling. excavators, steel fixing, lifting precast items, concreting equipment and road surfacing	Bored piling rig, excavators, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Transition structure construction (22 months)	Nil	Bored piling rig, excavators, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Road surfacing (4 months)	As for daytime but limited to areas of interface with existing ICB infrastructure	Delivery trucks, paving machine, compaction equipment, line marking

Noise Impacts

Night-time Construction of Cut and Cover Structures for ICB Connection

The following conclusions regarding noise impacts associated with night-time surface road works at the ICB connection are drawn from the assessment.

Normanby Terrace and Victoria Park Road Residences

- For Normanby Terrace and Victoria Park Road residences, the predicted LAeq(15minutes) and LAmax noise levels from the cut and cover construction works are up to 13 dBA and 11 dBA higher than the respective noise goals. During the night-time period, this would likely be found to be intrusive and possibly result in sleep disturbance at the nearest residences. It is likely that for some construction noise sources actual levels will be lower due to a greater barrier effect than the 5 dBA (broken line of sight) reduction applied to the results.
- On the basis of the predicted noise goal exceedances, it will be important to notify residents well in advance of all noise intensive night-time construction works.
- Insofar as possible, the majority of the construction works required to complete the ICB connection should be carried out during the daytime period so as to avoid sleep disturbance.

Daytime Construction of Cut and Cover Structures for ICB Connection

The following conclusions regarding noise impacts associated with daytime surface road works at the ICB connection are drawn from the assessment.

Normanby Terrace and Victoria Park Road Residences

- For Normanby Terrace and Victoria Park Road residences, the predicted LAeq(15minutes) noise levels from the cut and cover construction works are up to 16 dBA above the noise goal. It is likely that an exceedance of this magnitude would be found to be intrusive and possibly interfere with indoor amenity. It is likely that for some construction noise sources actual levels will be lower due to a greater barrier effect than the 5 dBA (broken line of sight) reduction applied to the results.

Brisbane Grammar School (Indoor Sports Centre)

- The highest Northern Link construction noise levels at Brisbane Grammar School are predicted to result during use of the rock drill and bored piling rig. Other construction noise sources are similar in level to existing ambient noise, primarily from the ICB, for this area.

Brisbane Girls Grammar School (Classrooms)

- The highest Northern Link construction noise levels at Brisbane Girls Grammar School are predicted to result during use of the rock drill. An exceedance of 12 dBA above the external noise goal is predicted during its use. Levels of this magnitude would be audible within classrooms and may interfere with internal activities. Further investigation of the attenuation through the façade of the school buildings closest to the construction works is recommended to further assess and mitigate noise impacts.

Noise Mitigation

The following noise control measures are recommended for mitigation of noise from the ICB connection construction works.

- Advance notification to the residents
- Select construction processes and plant to minimise construction noise
- Assist owners of properties nearest the construction site to temporarily upgrade the acoustical insulation and ventilation of rooms
- A detailed investigation of classroom facades at Brisbane Grammar and Brisbane Girls Grammar Schools to determine actual noise attenuation and therefore assess the need for further mitigation
- Early construction of the operational noise barriers to protect Normanby Terrace residences

Vibration Impacts

It is not anticipated that vibration levels associated with vibratory rolling during road surfacing of the Northern Link ICB connection will be significant.

8. Ventilation Infrastructure Construction

Western Outlet

Construction of the western ventilation outlet would be similar to the cut and cover tunnel construction activities and provided the outlet is located close to the Northern Link mainline tunnel impacts associated with these works would be similar in nature. For this reason no further assessment is required.

Eastern Connection

Construction of the eastern ventilation outlet would likely require a combination of driven tunnel (roadheader) near the extraction point and cut and cover close to the outlet point.

The following conclusions regarding noise impacts associated with ventilation station construction works are drawn from the assessment.

Victoria Park Road Residences

- The residents in Victoria Park Road will at times be located as close as 20 m from ventilation tunnel construction. As the works progress towards the outlet point this separation distance will increase to beyond 200 m.
- A large number of plant items required to carry out the works will likely exceed the external design goal during normal operation at the site. Exceedances of this nature are common when construction works occur in close proximity to receivers.
- It is important that the use of significant noise generating plant be minimised insofar as possible and that nearby residents are notified of the works in advance.

QUT Kelvin Grove Campus

- The highest construction noise levels at QUT are predicted to exceed the noise goal by a marginal 3 dBA. Levels of this magnitude are unlikely to be “intrusive” within classrooms. It was noted during the noise monitoring site visit that the nearest row of buildings to the proposed outlet site were not teaching areas.

Noise Mitigation

The following noise control measures are recommended for mitigation of potential noise from ventilation station construction works.

- Advance notification of the time, type and duration of works, especially any night works in the case of residential receivers.
- Select construction and plant to minimise construction noise.

Vibration Impacts

It is not anticipated that vibration levels associated with the eastern ventilation station construction will result in vibration impacts.

9. Tunnelling Between Portals

It is proposed that two Tunnel Boring Machines (TBM) will be used to excavate the mainline tunnel section between the Western Freeway launch pits to the ICB extraction pit. Roadheader and drill-and-blast excavation is likely to be used at the following locations:

- Toowong ramp connections including Frederick Street and Milton Road Y Junctions.
- Kelvin Grove Road ramp connection tunnels including the Kelvin Grove Road Y Junctions.
- Cross passages, low point sumps, substations etc.

Underground Tunnelling Between Portals

Roadheading

Predicted worst-case regenerated noise levels from roadheading exceed the AS2107 guide values for many residential receivers above the roadheader driven sections of the Northern Link tunnels. Sleep disturbance impacts are also likely to result from Northern Link on/off ramp tunnelling due to the shallow tunnel depths. All practicable mitigation measures will be required to minimise the impact from these works.

There are shallow tunnel areas at both the Toowong (on and off ramps) and Kelvin Grove (off ramp only) areas where vibration from roadheaders may be perceptible. No major on-going vibration mitigation measures or impact response management procedures are anticipated to be necessary for this type of tunnelling. It is recommended however that vibration measurements/monitoring be conducted during the start of the tunnelling works to confirm the predictions (based on the actual plant items being used) and to allay any concerns that the community may express.

Blasting

Only daytime blasting is envisaged for the project. Blasting generally results in short, strongly noticeable vibration lasting one to two seconds. The normal mitigation method in relation to human impacts is to give clear and concise pre-notification to all persons in the affected area.

Careful blast design is recommended to mitigate against building impacts, and if necessary, using gradually increasing trial blasts to establish safe design parameters. It is a requirement of Brisbane City Council to conduct pre- and post-blasting Building Condition Surveys where it is considered there may be potential for cosmetic building damage.

Tunnel Boring Machine

Worst-case predictions indicate that it is likely that regenerated noise from the TBM will be noticeable in many buildings above the tunnel alignment and may result in sleep disturbance. All practicable mitigation measures detailed in **Section 10.4.5** of the report are required to minimise the impact from these works.

Regarding vibration, sleep disturbance may result if the vibration levels from a continuous source are higher than 0.5 mm/s which is predicted to be the case for many residences above the mainline tunnels. It should be noted that the 0.5 mm/s night-time guideline vibration level for this project is conservatively low and some people may be comfortable with higher levels.

Vibration from the TBMs may potentially exceed the “damage” guide values at the Toowong Cemetery, the Charlotte Street area and the Normanby Terrace area. Building condition surveys should be conducted prior to the tunnelling works and monitoring during the works will be required.

Low Frequency Noise Impacts

The frequency range of infrasound is normally taken to be below 20 Hz and audible noise from 20 Hz to 20,000 Hz. Contrary to this interpretation, noise at frequencies below 20 Hz can be audible, however tonality is lost below 16 – 18 Hz thus losing a key element of perception. Low frequency noise spans the infrasonic and audible ranges and may be considered as the range from about 10 Hz to 200 Hz.

Guidance on the assessment of low frequency noise impacts can be sought from the (Queensland EPA) Ecoaccess Guideline *Assessment of Low Frequency Noise*. The intent of these criteria is to accurately assess annoyance and discomfort to persons at noise sensitive places. The guideline assesses both infrasound – below 20 Hz (Part A) and low frequency noise – above 20 Hz (Part B).

Part A – Infrasound (<20 Hz)

Recommended infrasound limit values are:

- 85 dB(G) inside dwellings during the day, evening and night and inside classrooms and offices.
- 90 dB(G) for occupied rooms in commercial enterprises.

Analysis based on a limited TBM and road header measurements on NSBT show that:

- A TBM operating at approximately 10 m from a receiver building may exceed the Ecoaccess guideline values. To achieve the recommended limit value for infrasound, a separation distance of 30 m is required for a TBM. A roadheader will comply at approximately 5 m.

It should be noted that very limited one-third octave spectral data exists for tunnelling operations in local strata and that the above analysis is based on initial results from NSBT measurements. Therefore it is recommended that further analysis be undertaken as additional one-third octave spectral data becomes available prior to finalising a mitigation strategy where infrasound is found to be an issue.

Part B – Low Frequency Noise (≥20 Hz)

The Ecoaccess low frequency noise assessment procedure involves the following:

- Initial Screening – NSBT TBM and roadheader measurement results, over slant distances of 30 m and 15 m respectively indicate that the 50 dB(Linear) level will be exceeded when tunnelling at close distance
- Audibility Assessment – It is recognised that regenerated noise from driven tunnelling plant will be audible at times during construction and therefore steps 3 and 4 of the Ecoaccess guideline are undertaken below.

- Annoyance due to Tonal Noise – The one-third octave band spectra from measurements of the NSBT TBMs and roadheaders do not exhibit tonality.
- Annoyance due to Non-tonal Noise

Analysis indicates that the recommended limits applicable to non-tonal low frequency noise will be exceeded for all receiver types when operating in close proximity.

At distances of approximately 190 m and 70 m (for TBM and roadheader respectively) or greater, compliance with the annoyance threshold ($L_{pA,LF}$ 20 dB) would likely be achieved for dwellings during the evening and night-time period.

As discussed, the spectral data used for the present assessment is based on a relatively small measurement sample. It is recommended that a detailed low frequency noise assessment be carried out for the Northern Link Project as additional data becomes available.

A management plan specifically for low frequency noise impacts will include, as a minimum:

- A comprehensive notification and education program to assist in allaying fears regarding tunnelling. Part of the education process will include an indication of tunnelling progress and subsequent likely (temporary) exposure periods.
- Infrasound and low frequency noise measurements in accordance with the Ecoaccess guideline at the commencement of tunnelling operations and in the event of a "low frequency" noise complaint (where required).
- An option for temporary relocation of people pending the outcome of an assessment of the impact against the EIS criteria and Ecoaccess "low frequency" noise guideline.

Mitigation of Vibration and Regenerated Noise from Tunnelling

The following impact management and mitigation strategies are recommended to minimise the impacts of tunnelling vibration and regenerated noise:

- Comprehensive advance notice as well as educating the public of intended tunnelling activities in the localities near the tunnel alignment. Part of the consultation process should include information regarding the monitoring program which may require involvement from residences located above the tunnel alignment. A thorough education program will assist to allay fears of the tunnelling process.
- Noise and vibration monitoring should be undertaken at the commencement of tunnelling to confirm that the source data utilised for this assessment is applicable to this project (including the low frequency noise assessment inputs and findings).
- Conduct pre- and post-blasting Building Condition Surveys in accordance with Brisbane City Council requirements where it is considered there may be potential for cosmetic (superficial) building damage from TBM and drill-and-blast methods.
- The option of temporary relocation of residents.

10. Construction Traffic

10.1 Construction Traffic

Spoil traffic would not increase average traffic noise levels on spoil routes by more than 0.2 dBA for existing significant road corridors. It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear and therefore negligible.

It is concluded that spoil traffic would not significantly impact on the noise environment of residential locations along the spoil routes that have been assessed.

Recommended Construction Traffic Mitigation Measures

Recommended construction traffic mitigation measures for Northern Link include:

- Best practice management over engine noise emissions by procurement and maintenance of a fleet that conforms to Australian Design Rule 28/01 for engine noise emissions, tested in accordance with the National Road Transport Commission document Stationary Exhaust Noise Test Procedures for In-Service Motor Vehicles.
- Adoption of airbag suspension throughout the fleet to minimise noise associated with empty trucks travelling over road irregularities.

Satellite tracking and management of the position of the truck fleet to ensure that waiting queues are appropriate to space constraints, minimising noise from idling trucks.

11. Health Effects Due to Construction Noise and Vibration

Construction Noise

As construction works associated with the Northern Link Project will occur in proximity to noise sensitive receivers it is inevitable that some people may experience annoyance as a result of the project. It is therefore imperative that construction noise be minimised insofar as possible through best practice measures, the community be kept informed of construction works in advance and that any complaints are promptly addressed.

The WHO Guidelines for Community Noise suggest that the risk for hearing impairment from any noise source would be negligible for $L_{Aeq, 24hr}$ values of 70 dBA over a lifetime. $L_{Aeq,24hr}$ values of 70 dBA are very unlikely to occur at any stage during construction of the Northern Link Project.

To avoid hearing impairment, impulse noise exposures should never exceed 140 dB peak sound pressure in adults and 120 dB peak sound pressure in children. The only activity during construction of the Northern Link that has the potential to exceed this limit is blasting.

Potential for sleep disturbance resulting from Northern Link construction works have been identified. As sleep is critical to restore biological processes, all practicable mitigation measures are required to minimise potential for sleep disturbance during out of hours Northern Link construction work.

Construction Vibration

The vibration assessment indicates that the human comfort limits (AS 2670) may at times be exceeded. Subsequently, it is important that construction vibration be minimised insofar as possible through best practice measures, the community be kept informed of construction works in advance, particularly tunnelling progress, and that any complaints are promptly addressed.

Vibration levels have been predicted for tunnelling operations between portals and have been assessed against the sleep disturbance guide level. In some areas above the Northern Link tunnels, the sleep disturbance guide level is predicted to be exceeded which indicates that sleep disturbance may result.

Anticipated vibration levels will be much lower than the calculated equivalent PPV where health risks may become an issue. Therefore, the health risk associated with generated vibration levels during construction may be considered extremely low.

Asbestos

Potential mechanisms for dislodging asbestos fibres due to construction vibration are:

- *Sheeting cracking and being damaged by vibration, leading to the generation of fine asbestos particles.*

  There are no asbestos concerns.
- *Vibration producing movement between abutting sheets leading to the generation of fine asbestos particles.*

  There are no asbestos concerns.
- *Vibration causing (settled) asbestos dust within the ceiling cavity to become dislodged and fall through cracks, vents, light fittings or other openings.*

  The recommended worst case scenario is that perceptible levels of vibration should be considered capable of dislodging settled asbestos dust. Accordingly, management techniques are recommended (where appropriate) as follows:

  - pre-construction inspections
  - pre-construction sampling of dust for identification of asbestos (where required)
  - removal of dust containing asbestos by licensed removalists
  - plastic sheeting installed in ceilings to collect dust
  - post-construction clearance inspections and associated sampling

These measures should form part of the Construction Noise and Vibration Environmental Management Plan.

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1. Introduction

1.1 Background

Heggies Pty Ltd (Heggies) has been commissioned by the SKM Connell Wagner Joint Venture (JV) to prepare an assessment of the construction noise and vibration aspects associated with the Northern Link project, for inclusion into the Environmental Impact Statement (EIS).

1.2 Terms of Reference

The specific requirements of the Terms of Reference[4] in relation to the construction noise and vibration impacts associated with the project are reproduced below.

> ***5.5 Noise and Vibration***
>
> ***5.5.1 Description of Existing Environment***
>
> *The existing noise environment should be assessed by;*
>
> - *Reviewing available data from any ambient noise monitoring in the study corridor; and*
> - *Identifying representative existing, committed and approved sensitive places potentially affected by noise or vibration from the project (which may include receptors beyond the study corridor boundary) and monitoring background noise and vibration for these locations;*
> - *Conducting additional baseline noise monitoring at selected locations; and*
> - *Describing existing levels of road traffic noise at representative sensitive places by preparing a 3D noise contour model of noise transmission from the road network in the study corridor boundary for the baseline year, year of opening (2014) and the traffic planning horizon (to 2026).*
>
> ***5.5.2 Potential Impacts and Mitigation Measures - Construction***
>
> *To assess construction impacts the following should be undertaken:*
>
> - *Identification and assessment of all noise and vibration sources which may arise from the construction of the project, including noise and vibration generated by tunnelling works, surface construction sites and ancillary activities (e.g. 'lay-down' areas, access roads), particularly in regard to sensitive places;*
> - *The potential environmental impact of noise and vibration at all potentially sensitive places within and around the study corridor, in particular, any sensitive places should be quantified and compared with objectives, standards to be achieved and measurable indicators;*
> - *Assessment should be made of the potential emission of low-frequency noise (noise with components below 200Hz) from major items of equipment and plant. If necessary, measures should be described for reducing the intensity of these components. Reference should be made to the Environmental Protection Agency's draft guideline, Assessment of Low Frequency Noise;*
> - *Proposals to prevent, minimise or mitigate these effects, including details of any screening, lining, enclosing or bunding of facilities, or timing schedules for construction and operations that would minimise environmental harm and environmental nuisance from noise and vibration;*
> - *Identification and assessment of significant noise impacts associated with potential spoil haulage routes and other construction vehicle movements;*
> - *Identification of mitigation measures to address construction noise and vibration impacts including operating hours, barriers etc.; and*

[4] Queensland Government's Department of State Development and Innovation, *Northern Link Project – Terms of Reference for an Environmental Impact Statement.*

- *Discussion of a noise and vibration monitoring program to be implemented during the construction period, including an identification of possible locations for the placement of noise and vibration monitoring equipment.*

This assessment is to be inclusive of noise and vibration impacts to or on critical or sensitive places and the Toowong Cemetery, and determine the ground vibration effects on grave sites and equipment within health care facilities.

1.3 Objectives

The objectives of this report in relation to the project description are to:-

- Address the acoustical requirements detailed in the project's Terms of Reference in relation to the construction phase of the project;
- Evaluate the construction noise and vibration impacts at sensitive locations in terms of planning levels identified in the EPP[Noise] and other Guidelines;
- Define noise and vibration criteria by which construction noise and vibration impacts at sensitive locations may be evaluated;
- Evaluate the extent of resulting impacts and the scope for the reduction of these impacts through reasonable and feasible mitigation strategies; and
- Recommend appropriate mitigation measures.

2. Impact Assessment Criteria

2.1 Community Values Relating to Noise and Vibration

The Queensland Environmental Protection (Noise) Policy 1997 defines the values to be protected as the qualities of the acoustic environment that are conducive to:

d. *The wellbeing of the community or a part of the community, including its social and economic amenity; or*

e. *The wellbeing of an individual, including the individual's opportunity to have sleep, relaxation and conversation without unreasonable interference from intrusive noise.*

Sleep

A person's ability to sleep is perhaps the most important value that can be impacted by noise and/or vibration. Noise and vibration effects on sleep are generally referred to as sleep disturbance.

Recreation

Recreation is an important aspect of a healthy lifestyle. Recreation may include time spent both indoors and outdoors. In terms of acoustic function, recreation may involve communication with others in verbal conversation or simple enjoyment of an outdoor or indoor soundscape.

Education and Work

The needs for education and work in relation to the acoustic environment relate to the need to be able to communicate effectively either face-to-face or by telephone, and the ability to think or focus on auditory information without undue intrusion from other sources of noise.

Evaluating Impacts

The impact of a project on community values relating to noise and vibration and is normally evaluated using statutory regulations and policies which describe acceptable levels of noise and vibration from various sources.

For types of noise for which specific levels are not listed in statutory regulations or policies, it is common to refer to relevant Australian or internationally recognised standards that define acceptable levels of noise and vibration in various human and structural contexts. Such standards can serve an advisory function to regulatory organisations and may be adopted by statutory authorities for the purpose of defining regulatory levels.

2.2 Noise Impact Assessment Goals

2.2.1 Standard Statutory Construction Noise Regulations

The Environmental Protection Amendment (No 2) Regulation 1999 (EPAR) requires that a builder or building contractor not to carry out building work on a building site in a way that makes or causes audible noise to be made from the building work:

f. *On a Sunday or public holiday, at any time; or*

g. *On a Saturday or business day, before 6.30 am or after 6.30 pm.*

When the activity is an Environmentally Relevant Activity (ERA) or has had an EIS prepared, the penalties as defined in the Regulation, including the time restrictions above, do not automatically apply. Environmental safeguards for such activities are determined on a project specific basis and are detailed in the project's Approval Conditions.

Thus, construction activity between the hours of 6.30 am to 6.30 pm Monday to Saturday, excluding public holidays is not normally subject to numerical noise limits, providing the machinery being used is in good working condition. This regulation is summarised in **Table 1**.

- **Table 1 Standard Noise Regulations for Construction Activity**

Day	Operating Constraint
Monday to Saturday	6.30 am – 6.30 pm – no numerical noise limits
Sunday, Public Holidays and all other times	Construction must be inaudible at noise sensitive locations

This project would involve some instances where construction activity would be required to be undertaken on a 24 hour basis and that would likely be audible outside of the regulated construction hours. Accordingly, the project would require approval to operate outside of the regulated hours[5].

2.2.2 Assessment Philosophy for Extended Construction Works

It is anticipated that the project would involve the operation of certain noise sources on worksites (eg temporary ventilation and spoil extraction to surface from tunnelling) on a 24 hour per day basis. Thus, these construction noise sources would begin to resemble a permanent rather than temporary feature of the noise environment at neighbouring noise sensitive locations. Based on experience from other similar projects, it is also unlikely that these sources could be made completely inaudible at night.

There are no established goals criteria in Queensland for the assessment of impacts associated with long-term construction noise sources, especially at night. It is suggested that assessment goals for long-term construction noise sources should reflect the noise environment that is considered acceptable for normal functioning of adjoining developments (eg residential, healthcare and educational uses).

Thus, the potential impacts of long-term construction noise sources have been assessed by comparison with the following goals:

4. Sleep disturbance goals contained in statutory guidelines and policies.
5. Recommended internal noise levels for various building uses specified in AS/NZS 2107: 2000 Acoustics – Recommended design sound levels and reverberation times for building interiors.
6. Comparison with the existing noise environment.

These goals are generally similar to those expressed in the Brisbane City Council's *Noise Impact Assessment Planning Scheme Policy* (NIAPSP), except that the above goals do not make any reference to 'background noise creep'. Background noise creep requires consideration where a locality is subject to various (continuous) noise sources from on-going development. However in this instance, as the proposed

[5] A function of this report is therefore to define the possible impacts associated with operation outside regulated hours to support the application for this permission.

construction works are not permanent, it would be unreasonable to apply a 'background creep' goals to this project.

It must be emphasised that the purpose of these goals is to enable an assessment of impacts to be made. This is distinctly different from the function of criteria in the normal application of NIAPSP, which is for setting design limits.

The specific goals for sleep disturbance, recommended noise levels for various building functions and comparison with existing noise levels are discussed in the following sections.

2.2.2.1 Sleep Preservation

Both the Brisbane City Council's *Noise Impact Assessment Planning Scheme Policy* (NIAPSP) and the Queensland Environmental Protection Agency's Ecoaccess Guideline *Planning for Noise Control* recommend maximum internal noise levels in sleeping areas to avoid sleep disturbance. The recommended maximum levels from these two policies are summarised in **Table 2.**

- **Table 2 Regulatory Guidelines for Avoidance of Noise-induced Sleep Disturbance**

Guideline	Recommended Maximum Internal LAmax	Recommended Maximum Number of Occurrences per Night
BCC NIAPSP[1]		
AS1055.1 Appendix A R1-R3 Categories	45 dBA	"must not regularly exceed"
AS1055.1 Appendix A R4-R6 Categories	50 dBA	"must not regularly exceed"
EPA Ecoaccess	"Approximately 45 dBA"	"no more than 10 to 15"

Note 1: Contained in the NIAPSP Draft Guideline 2001.

The "R-category" descriptions in AS1055.1 are somewhat subjective. R3 is described as "Areas with medium density transportation or some commerce or industry" and is tabulated with an average night-time (10.00 pm to 7.00 am) background noise level of 40 dBA (L_{A90}). R4 is described as "Areas with dense transportation or with some commerce or industry" with an average night-time (10.00 pm to 7.00 am) background noise level of 45 dBA (L_{A90}).

The NIAPSP approach to assessing sleep disturbance is preferred as it includes some recognition that sleep disturbance is a function of the background noise level in addition to the level of the intrusive sound.

Acceptable levels of steady or near-steady ("quasi-steady") noise for sleeping environments are recommended in Australian Standard AS2107 *Acoustics – Recommended Noise Levels and Reverberation Times for Building Interiors.* These are detailed below:

2.2.2.2 Functional Noise Levels for Various Building Uses

The maximum recommended internal noise levels specified in AS/NZS 2107: 2000 *Acoustics – Recommended design sound levels and reverberation times for building interiors* are shown in **Table 3** for a selection of building uses that may be relevant to building uses near construction sites.

Table 3 Selection of Design Noise Levels from AS/NZS 2107:2000

Type of Building Occupancy	Maximum Design Level LAeq(60second) (dBA)
Residential buildings (sleeping areas)	40 (near major roads) 35 (near minor roads)
Residential buildings (living areas)	45 (near major roads) 40 (near minor roads)
Place of Worship	40 (with speech amplification)
School music rooms	45
School teaching area	45
School library	50
School Gymnasium	55
Commercial buildings – office space	45
Commercial Buildings – retail space	50

The stated scope of AS/NZS 2107 applies to noise that is steady or quasi-steady in nature. In practice the design levels from AS/NZS 2107 are widely used by Councils (eg Brisbane City Council NIAPSP) and the Department of Main Roads[6] as design goals in relation to daytime and night-time traffic noise which demonstrates some fluctuations in noise level. Brisbane City Council also uses AS/NZS 2107 for the assessment of mechanical plant noise intrusion into new residential developments. A measurement period of between 15 minutes and 1 hour is normally used to evaluate the LAeq(15minutes) parameter. Thus the proposed use of AS/NZS 2107 levels for the assessment of relatively steady plant noise emanating from construction sites has some similarities to the utilisation of AS/NZS 2107 in contemporary assessments of traffic noise and of mechanical plant noise intrusion into dwellings.

Because the AS/NZS 2107 design levels are expressed in terms of the LAeq(15minutes) parameter, some variability in a noise source is implicitly included when the average level meets the design level. For residential receptors, the implicit variability permitted by the LAeq(15minutes) parameter can be problematic at night. For this reason, night-time noise sources need to be assessed against sleep disturbance goal for the LAmax parameter in addition to the AS/NZS 2107 LAeq(15minutes) levels.

2.2.2.3 Comparison with Existing Noise Levels

The use of existing noise levels for the assessment of noise impacts is a common impact assessment practice. The Brisbane City Council NIAPSP refers to this type of assessment as “Comparison of like parameters or descriptors”.

Adjustments are normally made to the source levels as per AS1055.1-1997 in order to account for the increased subjective loudness associated with noises that are particularly tonal or impulsive.

2.3 Vibration Impact Assessment Criteria

2.3.1 General

Given a sufficiently high vibration level the potential adverse effects of vibration in buildings generated by construction activities are threefold:

6 Queensland Department of Main Roads *“Road Traffic Noise Management - Code of Practice”*.

- o Occupants or users of the building may be inconvenienced or possibly disturbed;
- o The building contents may be disturbed or affected; and
- o Cosmetic or structural building damage may be induced.

Vibration criteria which are relevant to the disturbance of building contents are more stringent than criteria relating to cosmetic building damage. However, vibration criteria relating to human comfort are the most stringent. This is because people are able to “feel” vibration at levels much lower than those required to cause even superficial damage to the most susceptible classes of building.

Vibration criteria are also differentiated between short transient vibrations, such as those induced by blasting (of the order of one to two seconds), and more sustained vibrations such as those associated with tunnel boring, roadheading or rockhammering. The risk of human discomfort is generally lower for short duration vibrations. The risk of cosmetic building damage is also lower for short duration vibrations compared to continuous vibrations of the same magnitude. This is because short duration vibrations will be less likely to fully ‘excite’ resonant vibration responses in a building structure.

2.3.2 Property Impacts

2.3.2.1 Review of Design Standards

Most commonly specified “safe” structural vibration levels are designed to minimise the risk of threshold or cosmetic surface cracks, and are set well below the levels that have the potential to cause damage to the main structure. Examples of threshold or cosmetic cracking include minor non-structural effects such as superficial cracking in cement render or plaster.

In terms of the relevant vibration damage criteria, British Standard 7385:Part 2-1993 *Evaluation and Measurement for Vibration in Buildings* is a definitive standard against which the likelihood of cosmetic building damage from ground vibration can be assessed. Sources of vibration which are considered in the standard include demolition, blasting (carried out during mineral extraction or construction excavation), piling, ground treatments (eg compaction), construction equipment, tunnelling, road and rail traffic and industrial machinery.

BS 7385 sets guide values for building vibration based on the lowest vibration levels above which cosmetic damage has been credibly demonstrated. These levels are judged to give a minimal risk of vibration-induced cosmetic damage, where ‘minimal risk’ for a named effect is usually taken as a 95% probability of no effect. In this standard, the guide values for transient vibration judged to give minimal risk of cosmetic damage to residential buildings are 3.7 mm/s at 1 Hz, rising to 15 mm/s at a frequency of 4 Hz, increasing to 20 mm/s at a frequency of 15 Hz, then to 50 mm/s at a frequency of 40 Hz and above. Where the dynamic loading of a building caused by continuous vibration of foundations is such as to give rise to dynamic magnification of vibration between the foundations and other parts of the building due to resonance, especially at the lower frequencies where lower guide values apply, BS 7385 advises that guide values may need to be reduced by up to 50%.

An earlier reference than BS 7385, German Standard DIN 4150:Part 3-1986 (reissued in 1999 without substantive changes) also provides commonly referenced guidelines for evaluating the effects of vibration on structures. For vibration frequencies of less than 10 Hz, the DIN Standard give “safe levels” up to which <u>no cosmetic damage</u> due to vibration effects has been observed, ie 100% confidence. These levels for peak vibrations are 5 mm/s for dwellings and 3 mm/s for historic buildings (with preservation orders or the like).

In relation to historic buildings, BS 7385 notes that "*Important buildings which are difficult to repair may require special consideration on a case-by-case basis. A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive*." A classification of buildings is given in Annexure A of BS 7385: Part 1: 1990 with an indication of the relative resistance to vibration. In contrast, DIN 4150 automatically applies the lowest possible criterion to historic buildings without justification, based on the actual building sensitivity.

As opposed to the "minimal risk of cosmetic damage" approach adopted in BS 7385, the "safe levels" given in DIN 4150 are the vibration levels up to which no cosmetic damage due to vibration effects has been observed. However, BS 7385 states that, "*Some data suggests that the probability of damage tends towards zero at 12.5 mm/s peak component particle velocity. This is not inconsistent with an extensive review of the case history information available in the UK*."

The DIN 4150 levels are more conservative than BS 7385 (generally twice as stringent) to avoid a small risk of cosmetic cracking. In practical terms, this could mean half the rate of tunnelling advance in sensitive areas and therefore twice the duration of exposure of a given receiver. A perceived advantage of the use of the DIN 4150 criteria is that full compliance with the recommended vibration levels should avoid any vibration-induced cosmetic building damage.

2.3.2.2 Regulatory Requirements

The Queensland Environmental Protection (Noise) Policy 1997, (EPP (Noise)) defines acceptable vibration limits for blasting with 80% compliance in stating that:

> "*The noise from blasting is reasonable if, measured outside the most exposed part of an affected noise sensitive place*
>
> h. *the air-blast overpressure is not more than 115 dB(Lin Peak) for 4 out of any 5 consecutive blasts; and*
>
> i. *the ground vibration is*
>
> a. *for vibrations of more than 35 Hz - not more than 25 mm/s ground vibration, peak particle velocity; or*
>
> b. *for vibrations of not more than 35 Hz - not more than 10 mm/s ground vibration, peak particle velocity."*

Part 6 of the Brisbane City Council Local Law 5 - *Permits and Licences* specifies vibration limits for blasting. The key environmental management requirements of this are:

- *Provision of formal notification of intention to blast 24 hours in advance.*
- *Performance of pre- and post-construction building condition surveys for all buildings where the anticipated ground vibration level will be 10 mm/s peak particle velocity or greater.*
- *Compliance with the ground vibration limits shown in* ***Table 4.***

▪ **Table 4 Council Ground Vibration Limits – Part 6 of Local Law 5**

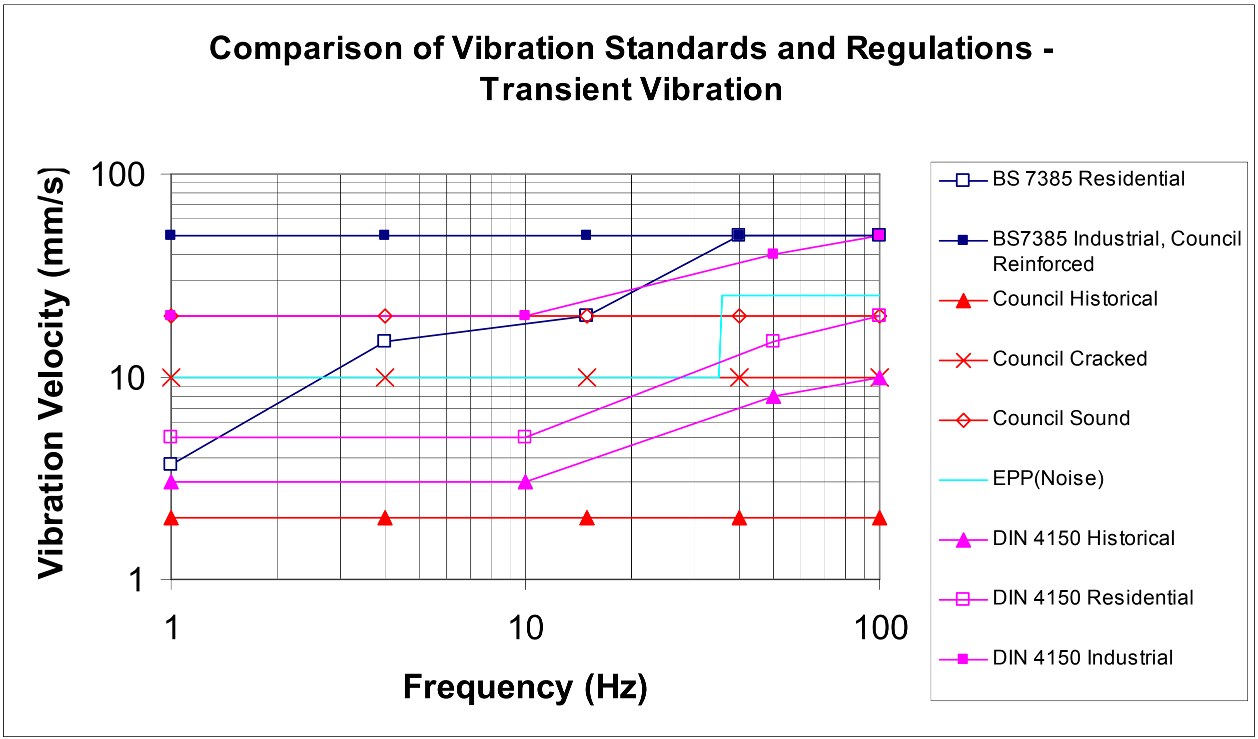
Type of Building or Structure	Ground Vibration Limit (peak particle velocity)
Historical buildings, monuments or ruin	2 mm/s
Visibly damaged or cracked buildings or structures	10 mm/s
Structurally sound buildings or structures	20 mm/s
Reinforced concrete or steel buildings or structures	50 mm/s

The Council vibration limits are not related to the frequency of the ground vibrations. As can be seen from the graphical comparison of all limits and recommended values illustrated in **Figure 1**, the simplification in the expression of the Council limits results in increased conservatism at high frequencies, but greater leniency at low frequencies where the potential for resonance-related building damage may be greater.

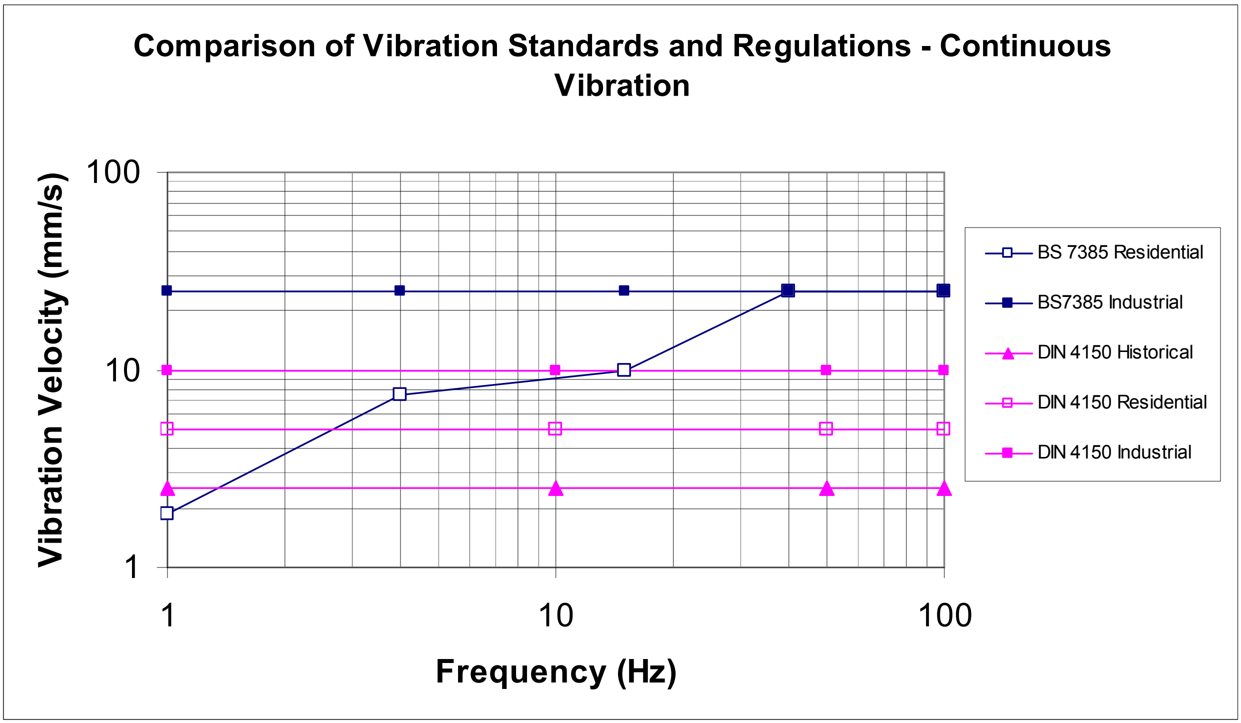
2.3.2.3 Comparison of Vibration Standards and Regulations

The vibration guide values and limits expressed in the standards and regulations discussed above are expressed graphically in **Figure 1** for transient or blast vibrations and in **Figure 2** for continuous vibration.

▪ **Figure 1 Comparison of Standards and Regulations – Transient Vibration**



- **Figure 2 Comparison of Standards – Continuous Vibration**



2.3.2.4 Levels for Assessment of Cosmetic Damage Potential

For impact assessment purposes, the EPP (Noise) limits for blasting (transient vibration) have been utilised for residential and other sensitive buildings. A 50% reduction of the guide values has been utilised to assess continuous vibration in line with the recommendation of BS 7385. The Council limit of 2 mm/s has been utilised for evaluating vibration levels at historical buildings. Guide values specific to reinforced structures have not been specifically referenced in this assessment of vibration as specific construction details of buildings are not known for all buildings along the corridor.

The assessment guide values for transient and continuous vibration in order to ensure a minimal risk of cosmetic damage to residential and other sensitive buildings are presented numerically in **Table 5**. It should be understood that these guide values are conservative, as the actual degree of tolerance of any building depends in a complex way on both the structural characteristics of the building and the frequency spectrum of the exciting vibration. At this stage of assessment, neither of these items of information are known in detail however, such information will likely act to increase the values in **Table 5**.

- **Table 5 Vibration Assessment Guide Values – Minimal Risk of Cosmetic Damage**

Vibration Type	Peak Particle Velocity (mm/s)		
	Heritage Listed	**Residential**	**Sensitive Commercial**
Transient Vibration (eg blasting)	2	10	10
Continuous Vibration (eg TBM, roadheading, rockhammering)	2	5	5

2.3.3 Building Contents

Over the frequency range typical of vibration in buildings from excavation and construction equipment (approximately 8 Hz to possibly 100 Hz), the threshold for visible movement of susceptible building contents (eg plants, hanging pictures, blinds, etc.) is approximately 0.5 mm/s. Audible rattling of loose objects (eg crockery) generally does not occur until levels of about 1 mm/s are reached.

In any premises, day-to-day activities (eg footfalls, closing of doors, etc) will cause levels of vibration in floors and walls that exceed 1 mm/s (sometimes by quite considerable margins), therefore visible movement and rattling are often observed. In most instances however, such movement is considered normal and vibration levels of even much greater magnitude do not result in damage to the objects or building contents.

Potentially vibration-susceptible building contents include sensitive instrumentation, computers and other electronic equipment, although such items are not usually kept in residences (apart from personal computers which are considerably more robust). Typical floor vibration levels for satisfactory operation of such sensitive items are presented in **Table 6**.

- **Table 6 Typical Satisfactory Vibration Levels for Sensitive Building Contents**

Equipment Type	Maximum Vibration Levels
Precision balances	0.5 mm/s to 2 mm/s
Some optical microscopes	0.5 mm/s
Large computer disk drives Sensitive electronic instrumentation	1 mm/s to 5 mm/s

Short-duration vibration events such as blasting may be permitted to cause somewhat higher vibration levels, depending on the vibration frequency content and on the specific susceptibility of particular items and their location.

Where particularly sensitive building contents have been identified, it is normal to undertake preliminary tests to establish the threshold of sensitivity before construction works proceed.

2.3.4 Human Comfort

In the previous section considering cosmetic building damage, the frequency of vibration excitation was important, as it related to the natural vibration frequencies of buildings and therefore the potential for building movement. In relation to human perception, it is the duration and time of day when the vibration occurs that is more important. Thus, human comfort vibration guidelines are expressed in terms of time of day and duration, rather than frequency.

2.3.4.1 Human Subjective Response to Vibration

Human tactile perception of vibration, as distinct from human comfort considerations, is summarised in German Standard DIN 4150 Part 2-1975. The degrees of perception for humans are suggested by the continuous vibration level categories given in **Table 77**.

▪ **Table 7 Vibration Levels and Human Perception of Motion**

Approximate Vibration Level	Degree of Perception
0.10 mm/s	Not felt
0.15 mm/s	Threshold of perception
0.35 mm/s	Barely noticeable
1.0 mm/s	Noticeable
2.2 mm/s	Easily noticeable
6 mm/s	Strongly noticeable
14 mm/s	Very strongly noticeable

Note: These approximate vibration levels (in floors of building) are for vibration having a frequency content in the range of 8 Hz to 80 Hz.

Table 77 suggests that people will just be able to feel continuous floor vibration at levels of about .15 mm/s and that the motion becomes "noticeable" at a level of approximately 1 mm/s.

2.3.4.2 Human Comfort Criteria for Continuous Vibration

Australian Standard AS 2670.2-1990 provides "human comfort" criteria for building use categories, including the following (in order of increasing sensitivity):

- Workshops
- Office
- Residential - day
- Residential - night
- Critical working areas – for example hospital operating theatres, precision laboratories etc.

The standard primarily defines vibrations guidelines in RMS (Root Mean Square). The units for velocity and acceleration are mm/s and mm/s^2 respectively. Satisfactory vibration levels are established with respect to human response as shown in **Table 8**.

▪ **Table 8 Vibration Criteria (RMS) – Human Comfort (from AS 2670:1990) – 8 Hz to 80 Hz**

Type of Space Occupancy	Time of Day	RMS Vibration Levels in mm/s corresponding to a Low Probability of Reaction			
		Continuous Vibration (16 h Day, 8 h Night)		Transient Vibration Excitation with several Occurrences per Day	
		Vertical	Horizontal	Vertical	Horizontal
Critical working areas (eg some hospital operating theatres, some precision laboratories, etc)	Day Night	0.1 0.1	0.3 0.3	0.1 0.1	0.3 0.3
Residential	Day Night	0.2 to 0.4 0.14	0.6 to 1.1 0.40	3 to 9 0.14 to 2	9 to 26 0.4 to 6
Offices	Day Night	0.4 0.4	1.2 1.2	6 to 13 6 to 13	17 to 37 17 to 37
Workshops	Day Night	0.8 0.8	2.3 2.3	9 to 13 9 to 13	26 to 37 26 to 37

The standard indicates that people (standing or sitting) in buildings are significantly less susceptible to horizontal vibration than to vertical vibration. The standard also indicates that people are more sensitive to continuous vibration than to transient vibration.

The satisfactory vibration levels presented in **Table 8** are based on the RMS or "root mean squared" vibration levels. The RMS is a vibration level averaged within a defined time period.

In order to determine corresponding allowable peak vibration levels that can be readily monitored during various construction activities, the RMS vibration levels need to be multiplied by an appropriate "crest" factor (ie ratio of the peak level to RMS level) to obtain a "peak" vibration level. Crest factors will vary from 1.4 for construction activities of a sinusoidal nature (eg continuous vibratory rolling and rotating plant) up to 4 or more for intermittent activities such as rockbreaking and blasting.

Table 9 presents the recommended "peak" vibration velocity levels to achieve "low probability of adverse comment" for continuous and transient vibration sources based on human comfort considerations.

- **Table 9 Recommended "Peak" Vibration Velocity Levels for Human Comfort**

Type of Space Occupancy	Time of Day	Peak Vibration Levels in mm/s corresponding to a Low Probability of Reaction			
		Continuous Vibration (16h Day, 8h Night)		Transient Vibration Excitation with several Occurrences per day	
		Vertical	Horizontal	Vertical	Horizontal
Critical working areas	Day or Night	0.14	0.4	0.14	0.4
Residential	Day Night	0.3 to 0.6 0.2	0.8 to 1.5 0.6	4 to 13 0.2 to 3	13 to 36 0.6 to 8.4
Offices	Day or Night	0.6	1.7	8 to 18	24 to 52

As can be seen from the last two columns of **Table 9** situations can exist where vibration magnitudes above those generally corresponding to a low probability of reaction, particularly for temporary disturbances and infrequent and intermittent events such as those associated with blasting, can be tolerated. With close cooperation and liaison with the occupants of the potentially affected properties, significantly higher levels of short-term vibration could be tolerated by many people for construction projects. In many instances there is a trade-off between the magnitude and duration of construction related vibration (eg rockbreaking versus blasting).

2.3.4.3 Sleep Preservation

It is difficult to define the level of vibration that would disturb sleep at night, as there is not a significant body of research that specifically investigates this issue. In practice, vibration in buildings that is considered to be disturbing is often perceived as structure-borne regenerated noise, noise generated by rattling objects, or through visual cues such as movement of wall hangings, rather than through tactile perception only. Often it is these effects that may make falling asleep difficult rather than actually disturbing a person out of a sleep state.

Nevertheless it is important to make an estimate of the threshold of vibration levels that may produce effects that disturb sleep, to identify geographical areas where specific attention may need to be directed in respect of night-time vibration.

For this purpose a vibration guide level of 0.5 mm/s (peak) has been estimated. This estimate is based on consideration of vibration levels commonly associated with the on-set of movement and rattling of building contents, vibration guide values based on human perception nominated in AS2670-1990, and the qualitative perception scale for continuous vibration outlined in German Standard DIN 4150 Part 2-1975.

The actual night-time response of individuals to vibration is difficult to predict and is usually altered by their level of understanding of the causes of vibration and the likely (or unlikely) effects, and their awareness of the project construction methods and timeframe. Some people may be comfortable with much higher levels of night vibration than the 0.5 mm/s estimate. It is important therefore that public consultation and education is conducted before and during tunnelling, combined with early vibration monitoring, to confirm actual vibration levels that are likely to avoid night-time sleep disturbance associated with tunnelling vibration.

2.3.5 Air-blast

2.3.5.1 Building Damage

Based largely on work carried out by the US Bureau of Mines, the US Office of Surface Mining has presented the following regulatory levels for airblast from blasting (depending on the low frequency limit of the measuring system):

- **Table 10 US Bureau of Mines Regulatory Levels**

Low Frequency Limit	Peak Airblast Level Limit
2 Hz or lower	132 dB Linear
6 Hz or lower	130 dB Linear

These levels are generally consistent with the level of 133 dB Linear nominated in AS 2187.2-1993.

The US criteria are based on relationships between the level of airblast and the probability of window breakage, and include a significant safety margin. It has been well documented that windows are the elements of residential buildings most at risk to damage from airblast from blasting.

While cracked plaster is the type of damage most frequently monitored in airblast complaints, research has shown that window panes fail before any other structural damage occurs (USBM, RI 8485-1980). The probabilities of damage to windows exposed to a single airblast event are as shown in **Table 11.**

- **Table 11 Probability of Window Damage from Airblast**

Airblast dB Linear	Level kPa	Probability of Damage	Effects and Comments
140	0.2	0.01%	"No damage" - windows rattle
150	0.6	0.5%	Very occasional failure
160	2.0	20%	Substantial failures
180	20.0	95%	Almost all fail

2.3.5.2 Human Comfort

The EPP (Noise) specifies a human comfort requirement of 115 dB (Linear Peak) for airblast.

3. Identification of Special Noise/Vibration Sensitive Buildings

Apart from the residential dwellings that are in the vicinity of the Northern Link connections and route alignment, there is a number of other noise/vibration sensitive locations that have been identified which have been considered in this report when assessing the potential for impacts arising from airborne or regenerated noise and vibration.

Relevant properties have been identified from a variety of sources including the social infrastructure study plans, general project information, site visits and a review of the latest UBD.

Table 12 lists the noise and/or vibration sensitive properties identified within the Northern Link project area. It is noted that some properties have been included, even though they may be considered to be some distance from the actual works.

- **Table 12 Special Noise/Vibration Sensitive Properties**

Type	Facility	Location
Aged Care	The Rosalie Nursing Care Centre	18 Howard Street, Rosalie
	Hilltop Gardens Aged Care	23 Rochester terrace, Normanby
Child care	C&K Rosalie Community Kindergarten and Preschool	cnr Nash & Elizabeth Street, Rosalie
Place of Worship	Toowong Baptist Church	5 Jephson Street, Toowong
	Brisbane New Church	21 Agars Street, Rosalie
	St Brigid’s Roman Catholic Church	78 Musgrave Road, Red Hill
	Toowong State School	St Osyth Street, Toowong
	Bible College of Queensland	1 Cross Street, Toowong
	Milton State School	Bayswater Road, Milton
Education	Marist College Rosalie	58 Fernberg Road, Paddington
	Petrie Terrace State School	Moreton Street, Paddington
	Queensland University of Technology (including Institute of Biomedical Innovation, Film and TV studio and proposed recording studio)	Kelvin Grove Campus
	Brisbane Grammar School	Gregory Terrace, Spring Hill
	Brisbane Girls Grammar School	Gregory Terrace, Spring Hill
	St Joseph’s College	285 Gregory Terrace, Spring Hill
Heritage	Toowong Cemetery	Mt Coot-tha Road, Toowong
	Brisbane Botanic Gardens	Mt Coot-tha Road, Toowong
Commercial	Red Cross	Kelvin Grove Urban Village
	LaBoite Theatre	Kelvin Grove Urban Village

Other places not specifically identified, such as community facilities, would be treated in the same manner as the surrounding residential properties.

4. Acoustic Terminology

4.1 Noise

The terms "sound" and "noise" are almost interchangeable, except that in common usage "noise" is often used to refer to unwanted sound. Sound (or noise) consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. The human ear responds to changes in sound pressure over a very wide range. The loudest sound pressure to which the human ear responds is ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms.

The symbols SPL, L or LP are commonly used to represent Sound Pressure Level. The symbol LA represents A-weighted Sound Pressure Level. The noise level descriptors that have been utilised within this report are illustrated in **Figure 3** and described below**.**

LAmax The maximum A-weighted noise level associated with a noise sampling period.

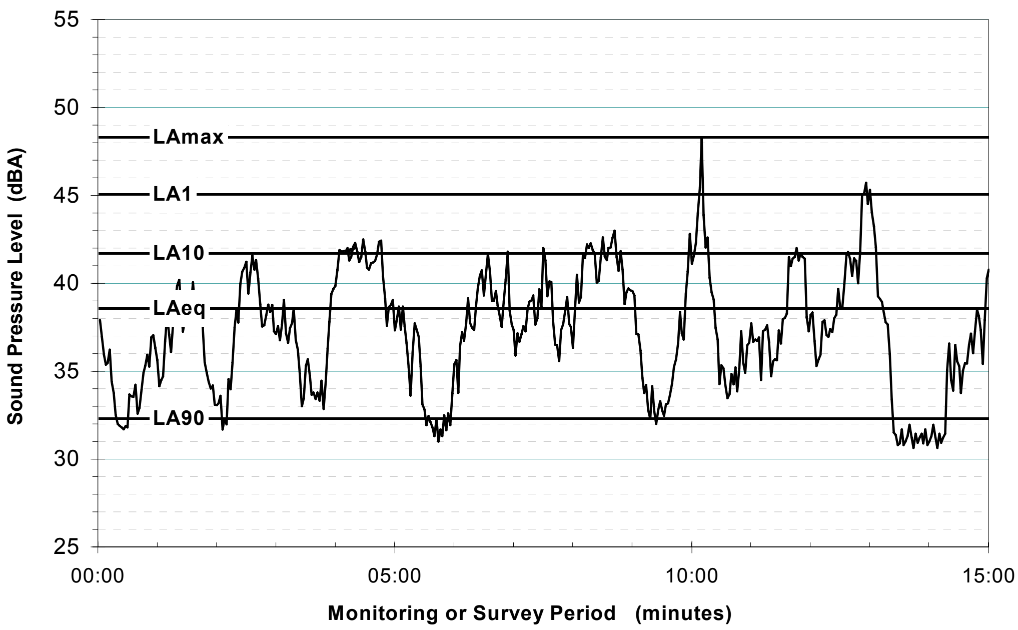
LA1 The noise level exceeded for 1% of a given measurement period. This parameter is often used to represent the typical maximum noise level in a given period.

LA10 The A-weighted sound pressure level exceeded 10% of a given measurement period and is utilised normally to characterise average maximum noise levels.

LAeq(15minutes) The average sound level. It is defined as the steady sound level that contains the same amount of acoustical energy as a given time-varying sound over the same measurement period.

LA90 The A-weighted sound pressure level exceeded 90% of a given measurement period and is representative of the average minimum background sound level (in the absence of the source under consideration), or simply the "background" level.

- **Figure 3 Graphical Display of Typical Noise Indices**



When dealing with numerous days of statistical noise data, it is sometimes necessary to define the typical noise levels at a given location for a particular time of day. A standardised method is available for determining these representative levels. This method produces a level representing the "repeatable minimum" background (LA90) noise level over the relevant daytime, evening and night-time periods, and is referred to as the Rating Background Level (RBL).

4.2 Vibration

Vibration may be defined as cyclic or transient motion. This motion can be measured in terms of its displacement, velocity or acceleration. Most assessments of human response to vibration or the risk of damage to buildings use measurements of vibration velocity. These may be expressed in terms of "peak" velocity or "rms" velocity. The former is the maximum instantaneous velocity, without any averaging, and is sometimes referred to as "peak particle velocity", or PPV. The latter incorporates "root mean squared" averaging over some defined time period.

Vibration measurements may be carried out in a single axis or alternatively as triaxial measurements. Where triaxial measurements are used, the axes are commonly designated vertical, longitudinal (aligned toward the source) and transverse. The common units for velocity are millimetres per second (mm/s).

People are able to "feel" vibration at levels lower than those required to cause even superficial damage to the most susceptible classes of building (even though they may not be disturbed by the motion). An individual's perception of motion or response to vibration depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as "normal" in a car, bus or train is considerably higher than what is perceived as "normal" in a shop, office or dwelling.

Human tactile perception of random motion, as distinct from human comfort considerations, was investigated by Diekmann and subsequently updated in German Standard DIN 4150 Part 2-1975. The resulting degrees of perception for humans (refer to **Table 77**) suggests that people will just be able to feel continuous floor vibration at levels of about 0.15 mm/s and that the motion becomes "noticeable" at a level of approximately 1 mm/s.

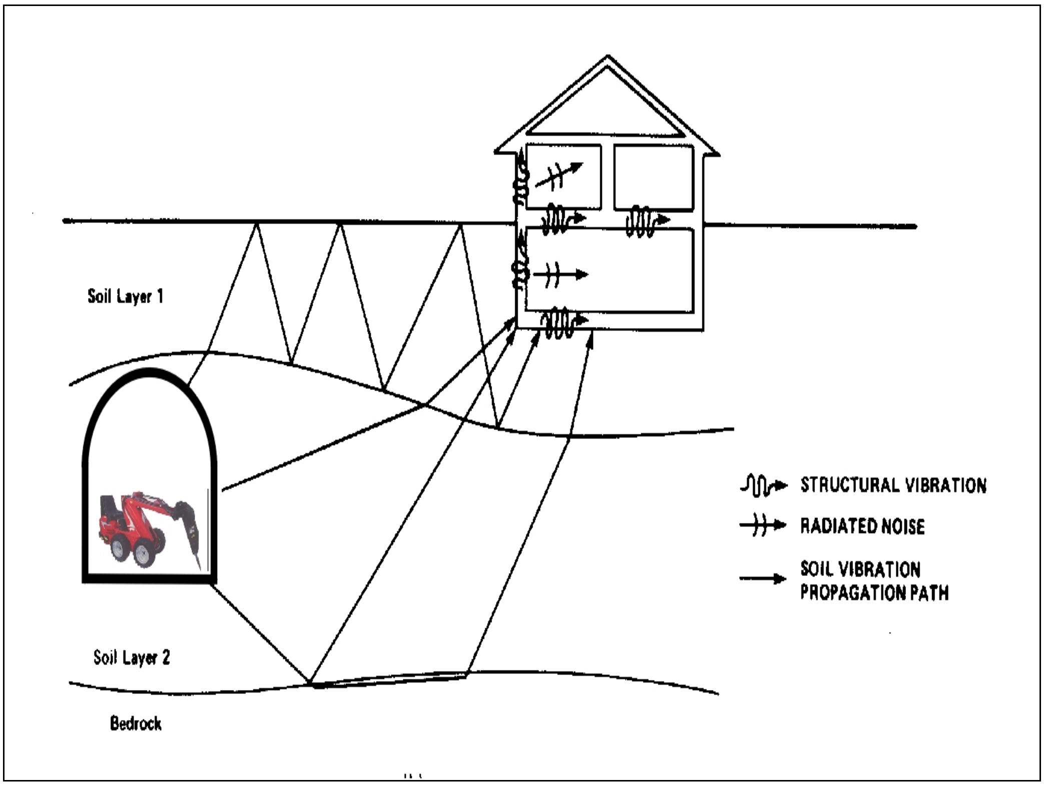
4.3 Regenerated Noise

Noise that propagates through a structure as vibration and is radiated by vibrating wall and floor surfaces is termed "regenerated noise", "structure-borne noise", or sometimes "ground-borne noise". Regenerated noise originates as vibration and propagates between the source and receiver through the ground and/or building structural elements, rather than through the air.

Typical sources of regenerated noise include tunnelling works, underground railways, excavation plant (eg rockbreakers), and building services plant (eg fans, compressors and generators).

Figure 4 presents the various paths by which vibration and regenerated noise may be transmitted between a source and receiver for construction activities occurring within a tunnel.

- **Figure 4 Vibration and Regenerated Noise Transmission Paths**



5. Existing Noise Environment

5.1 Introduction

A record of existing noise levels provides a baseline for assessment of potential noise emissions associated with construction and operational phases of the tunnel.

The aspects of the tunnel infrastructure that are of particular interest in respect of the existing noise environment are those areas in the vicinity of:-

- Construction sites,
- Ventilation Outlets, and
- Tunnel portals and associated connections.

The existing noise environment will be utilised to assist in the development of criteria for the assessment of noise impacts associated with the project, and be used to determine the reasonableness of providing noise control measures, where the base noise objectives are exceeded.

Existing ambient vibration levels at residences and other sensitive buildings are not normally significant. On maintained roads, ambient vibration levels on building foundations are generally below or near the minimum measurement threshold of regular vibration measurement instrumentation, and below the threshold of perception. A limited amount of ambient vibration measurements were conducted to verify the validity of this generalisation on this project.

The Terms of Reference required the existing noise levels to be described from available ambient noise records and additional noise measurements specifically targeted at assessing the noise environment around surface development associated with the project. In this regard available ambient noise records were found to be too site specific to relate to areas surrounding proposed surface developments. For this reason noise monitoring has been conducted at locations specific to surface developments associated with the project.

Information about the existing noise environment has been obtained from the following sources:-

- Site inspection during peak traffic periods and during quiet late-night periods;
- Unattended continuous measurement of sound pressure levels at eleven locations over a 7 day period.

5.2 Monitoring Sites

Noise monitoring sites have been selected to be representative of catchments that may be potentially affected by the Northern Link project. Site selection was focused mainly on residential receivers as they are generally the most noise-sensitive type of development in areas that may be affected by the tunnel.

Only the general location of tunnel portals, construction sites and vent stacks were known at the time of the initial noise logging program conducted during November 2007. Noise logging sites were therefore selected where the existing noise environment would be similar to that of the most exposed residential areas to the indicative locations of these tunnel features.

Development of the Northern Link reference design resulted in the need for two additional noise monitoring sites (Locations 13 and 14) which was completed in May 2008.

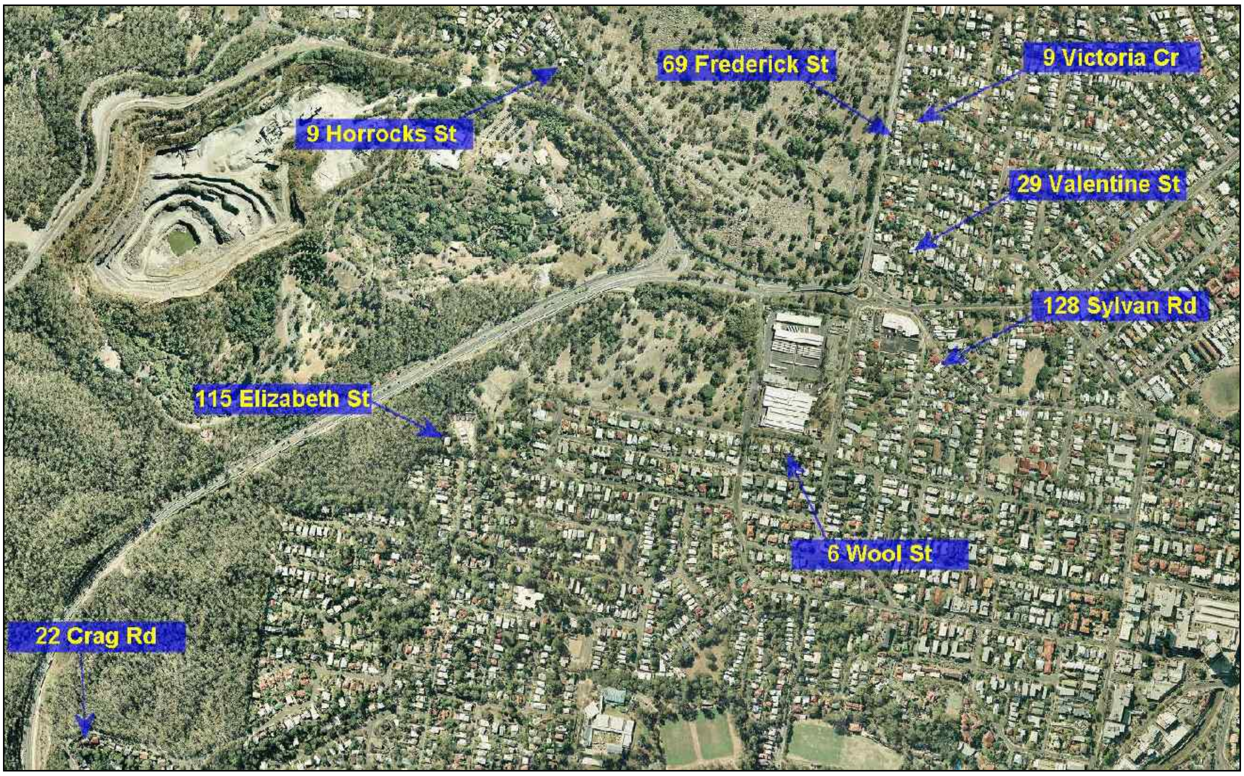
The details of the selected noise monitoring sites, and their relevance to potential tunnel noise issues is summarised in **Table 13**.

Figure 5 and **Figure 6** illustrate the noise monitoring locations for the Northern Link project. Photographs showing the noise logger position of each monitoring site are presented in **Appendix A**.

Table 13 Noise Monitoring Locations

Location Number	Monitoring Location	Relevance to Tunnel Noise Issues	Figure Reference
1	22 Crag Road, Taringa	Operational (surface traffic)	Figure 5 and Appendix A
2	115 Elizabeth Street, Toowong	Construction and operational (surface traffic and/or ventilation station) impacts associated with the western portal	Figure 5 and Appendix A
3	6 Wool Street, Toowong	Operational (ventilation station) impacts associated with western portal	Figure 5 and Appendix A
4	128 Sylvan Road, Toowong	Operational impacts associated with Frederick Street portal	Figure 5 and Appendix A
5	29 Valentine Street, Toowong	Construction and operational (surface traffic) impacts associated with Frederick Street portal	Figure 5 and Appendix A
6	69 Frederick Street, Toowong	Construction and operational (road traffic) impacts associated with Frederick Street portal	Figure 5 and Appendix A
7	9 Victoria Crescent, Toowong	Construction and operational (road traffic) impacts associated with Frederick Street portal	Figure 5 and Appendix A
8	5 Clyde Street, Brisbane City	Operational impacts associated with the eastern portals	Figure 6 and Appendix A
9	26 Lower Clifton Terrace, Red Hill	Construction and operational (road traffic and ventilation station) impacts associated with the eastern portals	Figure 6 and Appendix A
10	7 Westbury Street, Red Hill	Construction and operational (surface traffic) impacts associated with the Kelvin Grove portal	Figure 6 and Appendix A
11	Inner Northern Busway (INB), Normanby Station	Construction and operational (surface traffic) impacts associated with the Inner City Bypass (ICB) portal	Figure 6 and Appendix A
12	43 Normanby Terrace, Kelvin Grove	Construction and operational (surface traffic) impacts associated with the ICB portal	Figure 6 and Appendix A
13	9 Horrocks Street, Toowong	Construction and operational (surface traffic) impacts associated with the western portal	Figure 5 and Appendix A
14	QUT, Kelvin Grove Campus	Operational (ventilation station) impacts associated with the eastern portal	Figure 6 and Appendix A

- **Figure 5 Monitoring Locations surrounding Western Portals**



- **Figure 6 Monitoring Locations surrounding Eastern Portals**

5.3 Instrumentation

The instrumentation that was used for the noise monitoring is listed in **Table 14**. The calibration of all instruments was checked before and after monitoring and the difference in noise level was within 1 dBA in all instances.

All instruments were programmed to continuously record A-weighted fast response noise levels over 15 minute sampling intervals.

- **Table 14 Noise Monitoring Instrumentation**

Measurement Location	Instrumentation
All locations	Calibrator, Bruel &Kjaer Type 4231, S/N 2022772
1	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-529
2	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-299-426
3	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-506
4	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-508
5	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-509
6	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-508
7	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-299-426
8	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-301-471
9	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-525
10	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-524
11	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-529
12	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-525
13	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-505
14	Acoustic Research Laboratories Environmental Noise Logger EL316, SN 16-203-508

5.4 Results

5.4.1 Noise

The noise environment in the study corridor is typical of many inner urban areas, in that it is largely determined by road traffic noise. However, at some locations rail noise and/or mechanical plant noise are other significant sources.

Monitoring sites were inspected during morning or afternoon peak traffic times, the evening period and also during the late night/early morning period when background noise is typically quietest. The dominant audible sounds at each location are summarised in **Table 15**. As can be seen in **Table 15,** traffic noise from nearby major roadways was a dominant source of noise at all times of the day.

Table 15 Description of Existing Noise Sources

Location Number	Monitoring Location	Dominant Daytime & Evening Noise Sources	Dominant Noise Sources Late at Night
1	22 Crag Road, Taringa	Western Freeway traffic	Western Freeway traffic
2	115 Elizabeth Street, Toowong	Western Freeway traffic	Western Freeway traffic
3	6 Wool Street, Toowong	Western Freeway road traffic and mechanical plant and equipment noise from bus depot	Western Freeway and occasional Miskin Street traffic
4	128 Sylvan Road, Toowong	Milton Road and Sylvan Road traffic	Milton Road and Sylvan Road traffic
5	29 Valentine Street, Toowong	Milton Road and Frederick Street traffic	Milton Road and Frederick Street traffic
6	69 Frederick Street, Toowong	Frederick Street traffic and transformer noise	Frederick Street traffic and transformer noise
7	9 Victoria Crescent, Toowong	Frederick Street traffic	Frederick Street traffic and transformer noise
8	5 Clyde Street, Brisbane City	Musgrave Road and Hale Street traffic	Musgrave Road and Hale Street traffic
9	26 Lower Clifton Terrace, Red Hill	Kelvin Grove Rd and ICB traffic	Kelvin Grove Rd and ICB traffic
10	7 Westbury Street, Red Hill	Kelvin Grove Rd traffic	Kelvin Grove Rd traffic
11	Inner Northern Busway (INB), Normanby Station	Ithaca Street, ICB and INB road traffic and rail traffic (including freight)	Ithaca Street and ICB road traffic and rail traffic (including freight)
12	43 Normanby Terrace, Kelvin Grove	ICB road traffic and rail traffic (including freight)	ICB road traffic and rail traffic (including freight)
13	9 Horrocks Street, Toowong	Mt Coot-tha Rd and Western Freeway traffic	Western Freeway traffic
14	QUT, Kelvin Grove Campus	Victoria Park Road and ICB traffic	ICB traffic

Results of the noise logger measurements, in the form of a rating background level (refer to **Section 4.1** for a definition of Rating Background Level), are summarised in **Table 16** and provided in detail (including the prevailing weather conditions) in **Appendix B**.

The results in **Table 16** exclude noise monitoring results obtained during periods of high wind speeds (greater than 5 m/s) as recommended in AS 1055.1 and /or rain periods greater than 0.5 mm per 15 minute interval.

The operator-attended noise measurements are summarised in **Table 17**.

Table 16 Summary of (Unattended) Noise Logging Results

Locations		Description	Rating Background Levels minLA90 (dBA)		
			Day 7am – 6pm	Evening 6pm – 10pm	Night 10pm – 7am
1	22 Crag Road, Taringa	Front yard of detached single storey dwelling, facing Western Freeway	48	46	39
2	115 Elizabeth Street, Toowong	High side of front yard of detached highset dwelling, Toowong	46	41	34
3	6 Wool Street, Toowong	Front yard of single-storey detached dwelling, Toowong	47	41	37
4	128 Sylvan Road, Toowong	Front yard of block of units	49	44	35
5	29 Valentine Street, Toowong	Front yard (facing towards Milton Road) of detached highset dwelling	53	50	43
6	69 Frederick Street, Toowong	Front verandah of highset detached dwelling	61	48	35
7	9 Victoria Crescent, Toowong	Front yard of detached double-storey dwelling	48	43	35
8	5 Clyde Street, Brisbane City	Front patio of detached single-storey dwelling	54	51	43
9	26 Lower Clifton Terrace, Red Hill	Front yard of detached double-storey dwelling	58	56	45
10	7 Westbury Street, Red Hill	Front yard of detached single-storey dwelling	49	44	34
11	Inner Northern Busway (INB), Normanby Station	Located on parcel of Translink land between Ithaca St and INB east of Normanby Busway Station	56	51	40
12	43 Normanby Terrace, Kelvin Grove	Rear yard (overlooking ICB) of detached highset dwelling	53	52	39
13	9 Horrocks Street, Toowong	Low side yard of highset dwelling	51	48	37
14	QUT, Kelvin Grove Campus	Adjacent to south end of block Y1	47	45	43

Table 17 Summary of Operator-Attended (Short-term) Noise Measurements

Measurement Location	Date - Time	Period	LA10 (dBA)	LAeq (dBA)	LA90 (dBA)	Discernible Sources
1 – 22 Crag Road	Day	14/11/07 8:42	65	61	50	Traffic on Western Freeway and Crag Road
	Evening	14/11/07 20:15	55	55	49	Traffic on Western Freeway and Crag Road
	Night	15/11/07 1:00	50	49	39	Traffic on Western Freeway and Crag Road
2 – 115 Elizabeth Street	Day	14/11/07 9:04	49	51	43	Traffic on Western Freeway
	Evening	14/11/07 20:42	45	43	40	Traffic on Western Freeway
	Night	15/11/07 1:23	44	41	34	Traffic on Western Freeway
3 – 6 Wool Street	Day	14/11/07 9:27	57	56	46	Western Freeway road traffic and mechanical plant and equipment noise from bus depot
	Evening	14/11/07 21:04	54	52	49	Western Freeway and Miskin Street road traffic (resulting in higher background noise than during the daytime)

Measurement Location	Date - Time	Period	LA10 (dBA)	LAeq (dBA)	LA90 (dBA)	Discernible Sources
	Night	15/11/07 1:43	47	45	41	Western Freeway and Miskin Street road traffic
4 – 128 Sylvan Road	Day	14/11/07 9:48	67	64	51	Milton Road and Sylvan Road traffic
	Evening	14/11/07 19:53	66	61	48	Milton Road and Sylvan Road traffic
	Night	15/11/07 00:38	56	54	39	Milton Road and Sylvan Road traffic
5 – 29 Valentine Street	Day	14/11/07 8:12	59	57	54	Milton Road and Frederick Street traffic
	Evening	14/11/07 19:33	57	55	50	Milton Road and Frederick Street traffic
	Night	15/11/07 00:17	56	52	44	Milton Road and Frederick Street traffic
6 – 69 Frederick Street	Day	22/11/07 10:11	70	67	59	Frederick Street traffic and transformer noise
	Evening	26/11/07 20:54	64	59	42	Frederick Street traffic and transformer noise
	Night	27/11/07 00:31	60	57	39	Frederick Street traffic and transformer noise
7 – 9 Victoria Crescent	Day	22/11/07 9:53	58	55	48	Frederick Street traffic
	Evening	26/11/07 20:34	54	51	42	Frederick Street traffic and transformer noise
	Night	27/11/07 00:47	40	41	33	Frederick Street traffic and transformer noise
8 – 5 Clyde Street	Day	14/11/07 11:17	64	61	56	Musgrave Road and Hale Street traffic
	Evening	14/11/07 19:00	64	62	59	High volumes of traffic on Musgrave Road and Hale Street
	Night	15/11/07 2:09	56	53	41	Musgrave Road and Hale Street traffic
9 – 26 Lower Clifton Terrace	Day	14/11/07 10:32	63	60	54	Kelvin Grove Road and ICB road traffic
	Evening	14/11/07 18:14	64	62	57	High traffic volumes on Kelvin Grove Road (predominantly northbound) and ICB
	Night	15/11/07 2:28	54	51	40	Kelvin Grove Road and ICB road traffic
10 – 7 Westbury Street	Day	14/11/07 10:51	66	63	52	Kelvin Grove Road traffic
	Evening	14/11/07 18:34	61	58	50	Kelvin Grove Road traffic and noise from residents
	Night	15/11/07 2:45	53	50	40	Kelvin Grove Road traffic
11 – Normanby Station (INB)	Day	22/11/07 9:10	67	69	62	Ithaca Street, ICB and INB road traffic and rail traffic (including freight)
	Evening	26/11/07 19:56	67	65	62	Ithaca Street, ICB and INB road traffic and rail traffic (including freight)
	Night	27/11/07 1:28	61	59	37	ICB and Ithaca Street traffic
12 – 43 Normanby Terrace	Day	22/11/07 8:45	65	63	60	ICB road traffic and rail traffic (including freight)
	Evening	26/11/07 19:33	60	58	53	ICB road traffic and rail traffic (including freight)
	Night	27/11/07 1:11	56	52	38	ICB road traffic
13 – 9 Horrocks Street	Day	7/05/08 8:58	59	56	51	Mt Coot-tha Road and Western Freeway road traffic
	Evening	6/05/08 19:52	59	56	51	Mt Coot-tha Road and Western Freeway traffic
	Night	7/05/08 1:43	49	45	34	Western Freeway traffic
14 – QUT Kelvin Grove Campus	Day	7/05/08 8:13	57	55	51	Victoria Park Road and ICB traffic
	Evening	6/05/08 19:21	52	50	47	Victoria Park Road and ICB traffic

Measurement Location	Date - Time	Period	LA10 (dBA)	LAeq (dBA)	LA90 (dBA)	Discernible Sources
	Night	N/A	N/A	N/A	N/A	N/A

5.4.2 Vibration Measurements

In any premises, day-to-day activities (eg, footfalls, closing of doors, etc) will cause levels of vibration in floors and walls that exceed 1 mm/s (sometimes by quite considerable margins), and therefore visible movement and rattling are often observed. In most instances however, such movement is considered normal, and vibration levels of even much greater magnitude do not result in damage to the objects or building contents.

Vibration measurements were carried out at various locations to determine existing vibration levels prior to the start of construction using an Instantel Minimate Vibration Logger (Minimate S/N BE12563, geophone S/N BQ7806). All measurements were taken directly on the ground in the vicinity of the chosen receiver locations. The summarised results of the vibration measurements are documented in **Table 18**.

- **Table 18 Summarised Vibration Measurements**

Monitoring Location	Date - Time	Peak Component Particle Velocity (mm/s)	Dominant Frequency (Hz)
1 – Normanby Terrace (behind #43 near cycle path)	29/11/07 – 8:36	0.03	<1.0
2 – Normanby Terrace (adjacent to #9)	29/11/07 – 9:07	0.04	<1.0
3 – Normanby Busway Station	29/11/07 – 9:31	0.09	1.2
4 – Kelvin Grove Rd side of 25 Musgrave Rd	29/11/07 – 9:58	0.26	20
5 – Adjacent to 25 Upper Clifton Tce	29/11/07 – 10:31	0.09	<1.0
6 – Westbury St Kelvin Grove Rd intersection	29/11/07 – 10:56	0.11	N/A
7 – Toowong Cemetery (south-west corner)	29/11/07 – 11:48	0.05	<1.0
8 – Thorpe St Frederick St intersection	29/11/07 – 12:31	0.07	N/A
9 – In front of 5 Thorpe St	29/11/07 – 12:53	0.02	<1.0

These measurements show that at the majority of the monitoring locations the existing vibration levels are below the threshold level of human perception (~ 0.15 mm/s). The exception was at Location 4 where heavy vehicles travelling northbound along Kelvin Grove Road (down the hill from Musgrave Road) were generating vibration levels in excess of 0.2 mm/s (peak 0.26 mm/s) due to deformities in the pavement surface.

Existing vibration levels at the nearest corner of the Toowong Cemetery to the Western Freeway tunnel portal were at or below 0.05 mm/s.

6. Reference Noise and Vibration Data

6.1 Machinery Noise

A wide range of mechanical plant items are anticipated for the construction phase of the project. The specific size and selection of these plant items are not yet known, however typical items of plant have been nominated based on observations of similar tunnelling activities at existing worksites in the Brisbane region[7] and on indicative sizing of materials handling equipment that would be required to transport the spoil at the anticipated rates of tunnel excavation. Indicative source sound power levels have been obtained from AS 2436-1981[8].

A summary of these plant items, their function, likely location of use on the project and indicative sound power level are summarised in **Table 19.**

Sound power refers to the total rate of sound generation of a given item of plant. This quantity is independent of the distance from the plant item (analogous to the wattage power of a light-bulb) and allows direct comparison of the relative acoustic 'size' of different plant items. From this data, the sound pressure level (or noise level) at any offset distance from the plant can be calculated (analogous to the light intensity from a light-bulb – the greater the distance, the less intense).

It is proposed to enclose night-time noise sources within large enclosures in noise-sensitive areas to allow spoil accumulation on a 24 hour basis. In general, any enclosure is more effective at containing high-pitched noises (eg hisses, scrapes, whines) than low-pitched noises (eg thuds, deep exhaust notes). Therefore, to understand how effectively an enclosure will contain machinery noise, estimates are needed of both the frequency spectrum (or pitch) of noise sources and the frequency-dependent (or pitch-dependent) sound transmission characteristics of the enclosure.

Typical spectral shape data for representative types of noise sources that may be used within worksite enclosures are summarised in **Table 20**.

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7 North South Bypass Tunnel worksites.

8 Australian Standard 2436-1981 – Guide to Noise Control on Construction, Maintenance and Demolition Sites.

Table 19 Source Sound Power Level Estimates for Mechanical Plant

Description of Plant	Sound Power Level (LAmax dBA)	Plant Function	Possible Locations of Use
25t Articulated off-road Dump Truck	114	Underground spoil haulage from tunnel face	All areas of tunnel excavation
On-road Truck and Dog	103	Off-site spoil transport	All earthworks areas
20t, 100 kW Excavator	112	Spoil loading	Initial excavations of cut and cover areas and launch pits
35t, 200 kW Excavator	114	Surface excavation; rubble removal	Initial excavations of cut and cover areas and launch pits
200 kW Grader	116	Road grading	All surface connections
25t, 200 kW Front-end Loader	116	Spoil loading	All worksite enclosures
38t, 250 kW Dozer	118	Ripping and clearing	Initial excavations of cut and cover areas
600 kW Electric Conveyor Drive	106	Transport of spoil along tunnel to surface	Transport of spoil between EPB and spoil enclosures
Spoil Conveyor (Low Noise Idlers)	83 per metre	Surface transport of spoil from worksite	Western Connection to Mt Coot-tha quarry
Pneumatic Rock Drill	120	Pre-drilling for rock-bolting, drilling for explosives	All excavations in loose rock, all drill and blast operations
Large Air Compressor	103	Supply to rock drill	All drilling operations
Hydraulic Rockbreaker	120	Loosening rocky ground, trimming rock faces	All excavations in loose rock and all drill
20t Mobile Crane	105	Enclosure erection, loading/unloading	All worksites
Pile Boring Rig	118	Excavation for poured concrete piles	Edge of excavations in loose material, retaining walls and launch pits
24t Concrete Truck	112	Concrete delivery	All foundations, pouring of bored piles and shotcreting
Concrete Pump	107	Concrete delivery	All foundations, pouring of bored piles and shotcreting
Asphalt Paver	114	Road surfacing	All surface connections
Roller	104	Compacting and surfacing	All surface connections
100t Hydraulic Crane	110	Heavy lifting of elevated structure components	All surface connections
Water Truck	105	Dust suppression	Northern and Southern
Compressor 285 L/s	100	Power pneumatic tools	All worksites
Semi trailer	114	Delivery of construction equipment	All worksites
Bobcat	112	Spoil mucking	All worksites

Ventilation plant will also be a major item of plant that would operate at all worksites on a 24 hour basis. Sound power levels have not been listed for this plant since no indicative selections of construction ventilation plant have yet been determined. Further, the acoustic specification for this plant would normally be determined by site-specific acoustic constraints in accordance with the standard EPA's licensing requirements for fixed stationary noise sources. For this reason, a general indicative sound power level is not listed.

Table 20 Indicative Spectral Sound Power Distribution for Plant Located within Enclosures

Plant Type	Octave A-weighted Sound Power Levels Relative to Overall A-weighted Power Level (dB)							
	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Air Compressor	-27	-10	-6	-6	-9	-9	-14	-20
Diesel Powered Mobile Plant	-27	-20	-9	-7	-5	-6	-14	-24
Electric Conveyor Drive	-35	-22	-13	-9	-2	-12	-16	-32
Rock Drill	-23	-18	-15	-8	-6	-5	-7	-14

6.2 Acoustic Properties of Enclosure Materials

The amount by which acoustic energy is reduced as it passes through a material is known as the transmission-loss of the material. As discussed in the previous section, the transmission-loss is generally greater for high-pitched sounds than for low-pitched sounds.

Transmission-loss spectra for examples of possible enclosure construction materials are detailed in **Table 21**.

Table 21 Indicative Transmission Loss Spectra for Representative Enclosure Constructions

Material Description	Transmission Loss in Octave Bands (dB)							
	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
1 - Low Performance Option 0.62 mm metal decking	3	8	14	20	23	26	27	35
2 - Medium Performance Option 0.62 mm metal decking lined with 50 mm fibreglass[9]	5 (est)	10	15	22	32	37	43	43
3 - High performance Option 0.62 mm metal decking, 110 mm airspace, 50 mm fibreglass blanket in airspace, internal lining of 18 kg/m^2 porous-faced fibre-board[10]	15 (est)	20	29	43	46	57	63	63

The effectiveness of the possible enclosure materials listed in **Table 21** in reducing the types of internal noise sources shown in **Table 20** has been calculated. The results of these calculations are presented in **Table 23**.

Factors that maximise the effectiveness of an enclosure include the minimisation or avoidance of gaps or holes, effective mechanical isolation of the enclosure from pieces of machinery inside, and most importantly, the inclusion of sound absorption on internal surfaces of the enclosure.

An enclosure that has hard (non-absorptive) internal surfaces will cause what is described as reverberant build-up within the enclosure. This is noise that is reflected within the enclosure rather than being dissipated in acoustically absorptive materials (such as glass-fibre of poly-fibre linings - loose spoil also exhibits acoustical absorption). The more reverberant build-up of noise within the enclosure, the less effective the enclosure is in controlling noise because the inside noise level effectively increases.

The actual degree of absorption within the proposed enclosures is difficult to predict without an enclosure design and without information relating to the absorptivity of spoil.

9 Report No. 3668/159/4517B-5-83 in accordance with AS1276-1979 – Louis A. Challis & Associates Pty Ltd

10 Report No. 3798-1-82 – Louis A. Challis & Associates Pty Ltd

For indicative purposes the reverberant corrections described by Bies and Hansen[11] have been utilised. These corrections are reproduced in **Table 22.**

Table 22 Correction Factors for Internal Acoustic Conditions

Enclosure Internal Acoustic Conditions	Reverberant Corrections in Octave Bands (dB)							
	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Live (bare metal)	18	16	15	14	12	13	15	16
Average (absorptive lining of enclosure)	13	11	9	7	5	4	3	3
Dead (absorptive lining of all surfaces)	11	9	6	5	3	2	1	1

'Live' internal conditions would occur if all internal surfaces were hard, such as bare metal. This would occur for the Option 1 enclosure construction in **Table 23.**

'Average' internal conditions would occur if all internal surfaces of the enclosure were faced with a sound-absorptive material. Enclosure construction Options 2 and 3 in **Table 21** would achieve this**.** It is considered unlikely that acoustically 'dead' conditions would be achievable.

The effective noise reductions that would be achieved by alternative enclosure designs are summarised in **Table 23**. These estimates account for the spectral characteristics of sources (refer **Table 20**), enclosure constructions (refer **Table 21)**, and associated internal reverberant characteristics (refer **Table 22**).

Table 23 Effective Noise Reductions Achieved by Enclosure

Plant Type	Effective Noise Reduction (dBA)		
	1 - Low Performance enclosure	2 - Medium Performance enclosure	3 - High Performance enclosure
Air compressor	0	7	18
Diesel powered mobile plant	4	12	24
Electric conveyor drive	7	16	28
Rock drill	4	12	23

It can be seen in **Table 23** that a simple metal inclosure would achieve no overall noise level reduction for a noise source such as a compressor that has a noise emission dominated by low-frequency components. Overall, a bare metal enclosure should not be regarded as an effective noise control.

Substantial improvements in the effectiveness of an acoustic enclosure can be achieved by adding an acoustically absorptive internal lining (refer Option 2). A further substantial improvement can be achieved by effectively creating a double layer construction for walls and ceiling elements (refer Option 3).

It can also be seen from **Table 23** that the effective noise reduction can vary as much as 10 dBA depending on the frequency content of the plant item. Plant emissions that are dominated by high frequency noises, such as rockbreaking, will benefit most from an acoustic enclosure.

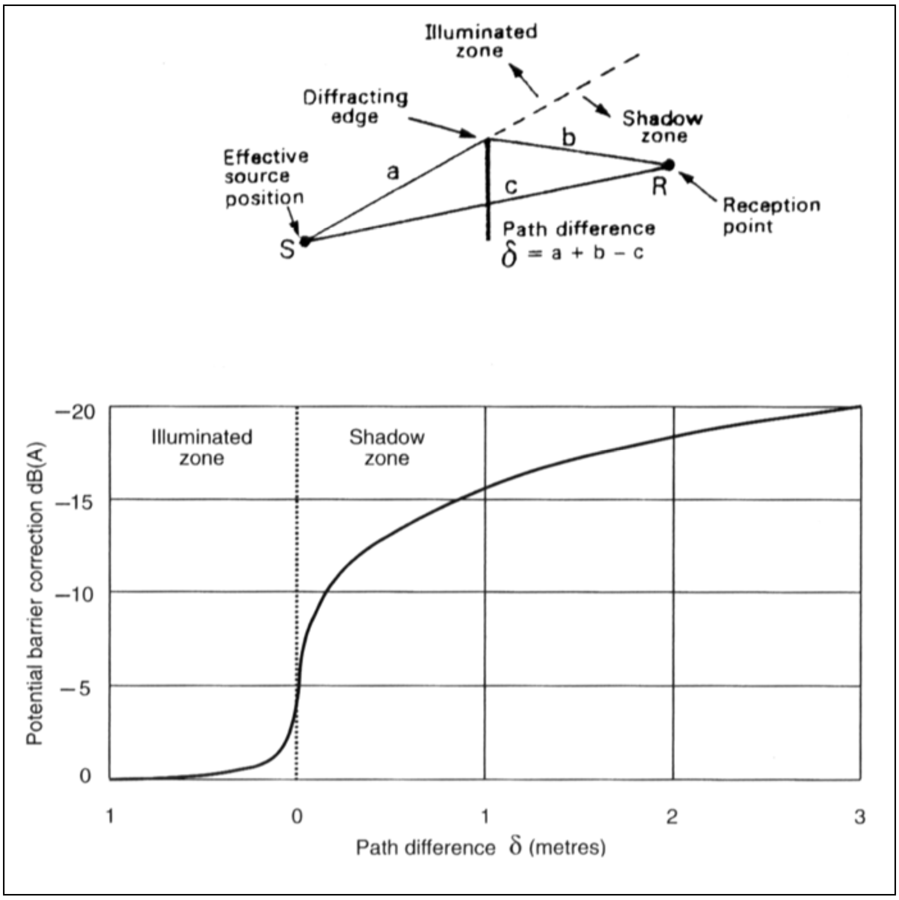
6.3 Indicative Effectiveness of Noise Barriers

The effectiveness of noise barriers typically ranges from 5 dBA if line-of-sight between the noise source and receiver location is just obscured, up to around 15 dBA where the barrier provides optimal blocking of the sound transmission path.

11 Engineering Noise Control – D.A. Bies & C.H. Hansen (1988)

The actual degree of attenuation will depend on the frequency spectrum of the noise and the length of the diffracted noise path compared with the direct noise path. For a noise spectrum dominated by sound in the range of 300 to 500 Hz, the relationship between the barrier attenuation and geometrical parameters is illustrated on **Figure 7**.

- **Figure 7 Geometric Dependency of Barrier Attenuation**



For this project it is very difficult to generalise about the degree of barrier shielding that would likely result from the erection of noise barriers near construction sites. Construction site barriers are typically in the range of 2.4m to 3.0m high. In general, the dwellings near construction areas for this project are either highset or Queenslander buildings. This gives a nominal receptor height of 3m or higher.

The effective height of noise sources will vary depending on the type of machinery in use and the exhaust height. For a pile-boring rig as an example, this height may be around 3 to 4m. For a front-end loader or excavator, the effective source height may be in the range of 2 to 3m.

Thus it can be seen that for many construction noise sources typical barriers in the range of 2.4m to 3.0m high would not obscure line-of-sight and would therefore not produce significant attenuation. The height of temporary barriers may therefore need to be 5 to 6m high in many instances to provide optimal noise reductions.

6.4 Indicative Effectiveness of Upgrading Building Facades

The following analysis of potential construction noise impacts in residential buildings is based on the assumption that the noise level difference outside a dwelling to inside a habitable room is a nominal 10 dBA for older type dwellings that rely predominantly on natural ventilation through windows, and

20 dBA for modern residential apartments with close-fitting sliding windows that would normally be equipped with air conditioning. For older dwellings it would be possible to increase the inside/outside noise level difference by 10 to 20 dBA.

This type of improvement would require a combination of the following physical changes to windows facing construction sites:-

- Retrofitting or replacing window seals,
- Closing windows,
- Fitting a secondary sliding window system, or alternatively replacing the existing window system.

Installation of ceiling fans and/or an air-conditioner system (window-mounted or split-type) and/or silenced fresh air ventilators may be appropriate to compensate for the loss of thermal comfort and natural ventilation that may occur if windows were kept closed.

For modern residential units, inside/outside noise level differences of up to 10 dBA higher than the nominal assumed value of 20 dBA may already be achieved if facades have already been design for control of traffic noise.

To give an exact prediction of possible gains in inside/outside noise level differences requires specific knowledge about the construction of individual dwellings. This could be achieved within the context of a detailed noise management plan.

6.5 Vibration

6.5.1 General Considerations

Different excavation methods generate different patterns of vibration. Conventional blasting can produce very short periods of vibration associated with each blast per shift. This could mean one blast each 12 hours during blasting operations. Blasting would normally be complimented by rockbreaking to trim the excavation envelope.

The milder form of blasting known as Penetrating Cone Fracture or PCF blasting (also referred to as Gas Blasting) does not require the same degree of evacuation as conventional blasting. In theory, PCF blasting could be undertaken to achieve smaller, more frequent blasts.

Rockbreaking normally involves periods of operation interrupted by manoeuvring and clearing by an excavator. Tunnel boring machines and roadheaders, on the other hand, generate relatively constant vibration levels during sustained periods of operation.

The vibration levels generated at the surface of the ground during surface or tunnel excavation is a function of many variables, including the excavation method, advance rate, depth below surface, ground (rock) hardness and the structure of surface strata. With limited strata information available before construction, it is difficult to predict exactly what vibration levels may be experienced. In this circumstance, it is usual to collate the highest vibration levels recorded for a range of extraction methods in similar circumstances. A consequence of this approach is that actual vibration levels may be lower than the predicted levels.

6.5.2 Reference Vibration Levels

6.5.2.1 Drill and Blast

Vibration levels from blasting do not represent a constant vibration source. To a greater degree than mechanical excavation methods, the design of a blast can be controlled to ensure that vibration levels remain within specified bounds. The extraction rate of advance is therefore dependent on the size and design of blasts.

Indicative blast vibration levels associated with tunnelling have been sourced from measurements carried out during the trial blasting for Brisbane Rail Tunnel Duplication[12]. These trials were conducted at the Creek Street tunnel portals that were excavated in hard rock. Vibration transducers were located on the foundations of nearby buildings, including the Incholm Building on Wickham Terrace and All-Saints Anglican Church on Anne Street. The correlation obtained from this study is:

$$\text{Vibration, V (mm/s)} = 14655 \times \{Q^{0.5}/R\}^{2.27} \quad \text{(RHA Q02-R1)}$$

Where R = distance (m) and Q = maximum instantaneous charge (kg).

A second estimate of blast vibration levels has been obtained from the ICI Explosives Blasting Guide[13] for tunnel blasts. The prediction formula from this guide would suggest lower vibration levels than the data from the Brisbane Rail Tunnel Duplication project. This relationship, for 80 percentile peak vibration levels, is:-

$$\text{V (mm/s)} = 608 \times \{Q^{0.5}/R\}^{1.6} \quad \text{(ICI Tunnelling).}$$

Table 24 shows the indicative permissible blast sizes that could result in a ground vibration velocity level of 2 mm/s at the building foundations. A limit of 2 mm/s is specified by the Brisbane City Council local laws for blasting near heritage-listed buildings.

Table 25 shows the indicative permissible blast sizes that could result in a ground vibration velocity level of 5 mm/s at the building foundations. A level of 5 mm/s would typically relate to commercial buildings containing sensitive equipment. Based on the normal frequency spectra associated with blasting, vibrations are likely to contain dominant frequencies above 3 Hz.

- **Table 24 Indicative Permissible Maximum Instantaneous Charge (MIC) to Achieve 2 mm/s PPV Near Heritage Structures – Conventional Blasting**

Data Source	Indicative Permissible Charge weight (kg) Versus Distance					
	Exceedance	**5 m**	**10 m**	**20 m**	**30 m**	**40 m**
General ICI Tunnelling formula	20%	0.02	0.08	0.03	0.07	1.3
QR Rail Tunnel trial blasts	20%	0.01	0.04	0.15	0.35	0.6

12 Heggies Pty Ltd Report Q02-R1, 1 June 1990 "Trail Blast Monitoring and Site Law Development – Duplication of Brisbane Inner City Rail Tunnels" Prepared for Connell Wagner (Qld) Pty Ltd

13 ICI Explosives Blasting Guide – Technical Services, ICI Explosives, October 1995.

Table 25 Indicative Permissible Maximum Instantaneous Charge (MIC) to Achieve 5 mm/s PPV Near Buildings with Sensitive Equipment – Conventional Blasting

Data Source	Indicative Permissible Charge weight (kg) Versus Distance					
	Exceedance	5 m	10 m	20 m	30 m	40 m
General ICI Tunnelling formula	20%	0.06	0.25	1.0	2.2	4.0
QR Rail Tunnel trial blasts	20%	0.02	0.09	0.35	0.8	1.4

Table 26 shows indicative permissible blast sizes that could result in a ground vibration velocity level of 10 mm/s PPV. This level would relate to residential dwellings and other buildings not containing highly sensitive equipment.

A 20% exceedance level has been reported for consistency with the blasting criteria in the EPP (Noise).

Table 26 Indicative Permissible Maximum Instantaneous Charge (MIC) to achieve 10 mm/s PPV Near Residential Dwellings and other Buildings – Conventional Blasting

Data Source	Indicative Permissible Charge weight (kg) Versus Distance					
	Exceedance	5 m	10 m	20 m	30 m	40 m
General ICI Tunnelling formula	20%	0.15	0.6	2.3	5.3	9.4
QR Rail Tunnel trial blasts	20%	0.04	0.16	0.65	1.4	2.6

In recent years, Penetrating Cone Fracture (PCF) blasting technology has been developed for rock excavation where vibration (and/or airblast) constraints are critical. In suitable rock formations the more efficient fracture mechanism employed by PCF allows vibration levels to be approximately half that of conventional explosives for the same volume of broken rock (or alternatively double the extraction for comparable vibration levels).

The PCF technique also dramatically reduces flyrock issues and airblast. PCF may therefore have advantages where blasting is required close to the surface (eg excavation of tunnelling access shafts at worksites) as well as for tunnel blasting beneath sensitive areas.

Charge sizes per blasthole for PCF technology typically range from 10 grams to 300 grams. Minimum charge sizes for conventional blasting are upwards of 120 grams per blasthole.

6.5.2.2 Tunnel Boring Machines (TBMs)

The proposed TBMs are approximately 12 m in diameter. TBMs of this diameter have only recently been employed for the first time in Brisbane (in hard rock) for the North South Bypass Tunnel. The hardest rock expected for the Northern Link is spillite of Bunya phylitte, with uniaxial compressive strength (UCS) values typically in the range of 70 MPa to 100 MPa.

Likely ground vibration levels for the Northern Link TBMs are shown in **Table 27.** These levels have been inferred from data measured by Nishimatsu Construction Co Ltd during tunnel boring for the Dublin Port Tunnel Project (in the UK)[14]. This project employed an 11.8 m diameter TBM to bore through limestone of UCS 140 MPa beneath 400 residential properties at tunnelling depths comparable to those planned for Northern Link.

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[14] Dublin Port Tunnel Project Office, Nishimatsu Construction Co. Ltd "Dublin Port Tunnel – Excavation of an 11.8m diameter urban motorway tunnel" - Proceedings of 30th International Tunnelling Association Congress, Singapore, 22-27 May 2004.

6.5.2.3 Roadheaders and Rockbreaking

The typical maximum levels of ground vibration from heavy roadheading and rockbreaking operations are also listed in **Table 27.** The frequency content of the ground vibration associated with roadheaders and rockbreaking is normally concentrated between 10 Hz and 50 Hz. These vibration levels have been determined from field vibration measurements collated by Heggies.

A summary of vibration levels anticipated from mechanical tunnel excavation methods are shown in **Table 27.** Vibration levels associated with conventional blast charge sizes are also included for comparison purposes.

From **Table 27** it can be seen that vibration levels associated with road headers are very low in comparison to other excavation methods.

- **Table 27 Indicative Maximum Ground Vibration Levels for Mechanical Tunnel Excavation Methods**

Operation	Peak Vibration Levels (mm/s) Versus Distance					
	5 m	10 m	20 m	30 m	40 m	50 m
12 m hard rock TBM	35	10	3	1.5	0.8	0.5
Heavy Rockbreaking	4.5	1.3	0.4	0.2	0.14	0.1
Heavy Roadheading	0.5	0.13	0.04	0.02	0.01	0.01
Blasting - ICI tunnelling formula						
5 kg Maximum Instantaneous Charge	168	55	18	10	6	4
1 kg Maximum Instantaneous Charge	46	15	5	2.6	1.7	1.2
0.2 kg Maximum Instantaneous Charge	13	4.2	1.4	0.7	0.5	0.3

6.6 Regenerated Noise

Regenerated noise refers to noise that is first transmitted to the ground by machinery as vibration which then travels to a sensitive location (such as a house) through the ground and foundations, where the walls, floor and ceiling then radiate this vibration as audible noise.

Regenerated noise levels are more difficult to predict than noise that is transmitted through the air only. This is because the transmission of regenerated noise depends on the ground strata, coupling between the ground and buildings and internal acoustical characteristics of buildings.

An indicative summary of regenerated noise levels anticipated from mechanical tunnel excavation methods is presented in **Table 28** based on a -30 x $\log_{10}$(distance) relationship[15] between distance and regenerated noise level.

15 Sound pressure is related to vibration velocity as 20 x $\log_{10}$(V), in the ground, vibration velocity varies with distance$^{-1.5}$ as an approximation across a range of rock conditions. (The exponent can typically vary from -0.5 to -2.5) depending on the particular rock conditions.) Combining these, the sound pressure is related to distance as -30 x $\log_{10}$(distance).

Table 28 Indicative Regenerated Noise Levels for Mechanical Tunnel Excavation Methods

Operation	Regenerated Noise Levels (dBA) Versus Distance					
	5 m	10 m	20 m	30 m	40 m	50 m
12 m hard rock TBM (based on Dublin Port Tunnel estimate of 55 dBA at 23 m, and Wilkinson Murray data for 7.2m TBM in sandstone, factored up for size, assuming vibration velocity is proportional to TBM face area)	69 - 75	60 - 66	51 - 57	45 - 51	42 - 48	39 - 45
Roadheading (Wilkinson Murray 38dBA @ 20m)	56-62	47-53	38-44	32-38	29-35	26-32
Rockbreaking (RHA 60 dBA @ 10m)	69-75	60-66	51-57	47-53	42-48	39-45
Rockdrilling (RHA 38dBA @ 23m)	58-64	49-54	40-46	36-42	31-37	29-35

The lower bounds of regenerated noise levels shown for rock drilling and roadheading presented in **Table 28** are based on field measurements for sandstone rock conditions in the Sydney area. Based on a comparison of regenerated noise levels from TBMs in hard and sandstone rock conditions, it is estimated that these regenerated noise levels may increase by up to 6 dBA for hard rock conditions.

7. Assessment of Work Sites

7.1 Modelling Methodology

This assessment provides an assessment of the acoustical impacts from the site preparation and construction works associated with the project. At this stage of the project, there has been no detailed assessment of the construction methodology however, it is still possible to provide a good estimate of the noise emissions based on reference sound power levels for typical items of plant and the anticipated location of plant at each worksite.

With the exception of the western connection worksite (adjacent the Botanical Gardens), worksites for this project are relatively confined, preventing a large number of plant items from operating simultaneously. In general it is considered that one plant item will dominate at any given time since processes such as excavation and loading will generally occur sequentially.

Indicative noise emissions from worksites have been assessed by the following process:

1. Establish typical daytime and night-time operating scenarios in consultation with the JV.
2. Identify representative receptor locations around worksites.
3. Calculate external noise goals at receptor locations based on internal noise assessment goals specific to the nature of the receptor.
4. Calculate maximum external noise levels at receptor locations from individual plant items, taking into account effects of distance (hemispherical spreading assumed) and where relevant, the effective noise reduction provided by an acoustic enclosure. For simplicity, no attenuation has been allowed for from site hoardings or other structures (other than existing road traffic noise barriers) that may provide barrier shielding[16]. Meteorological effects are not included as they are not relevant in the near-field zones upon which this assessment focuses.
5. The predicted maximum noise levels are converted to an LAeq(15minutes) index by the subtraction of 8 dBA for most plant items. Steady state noise sources such as conveyors were subtracted by 3 dBA.
6. Compare the predicted LAeq(15minutes) levels with the external noise goals to determine significance of potential impacts.
7. Specific mitigation strategies have been developed after analysis of noise emissions for the day and night operating scenarios. In this way mitigation strategies have been based on the most critical operating scenario.

The noise emissions from each worksite have been assessed for three scenarios:- site preparation, daytime tunnelling and night-time tunnelling. Of these scenarios, site preparation will take the least amount of time but frequently results in the highest noise emissions at adjoining locations. An assessment of noise levels from earthworks would not normally be undertaken for a building construction site during daytime operations. However, in this instance the initial earthworks are only the beginning of a much longer

[16] The barrier shielding that would be afforded by perimeter hoardings is highly dependent on the relative height of the receiver, the ground level at the barrier and the source noise height.

construction operation, and have therefore been assessed in the same way as day and night-time tunnelling operations.

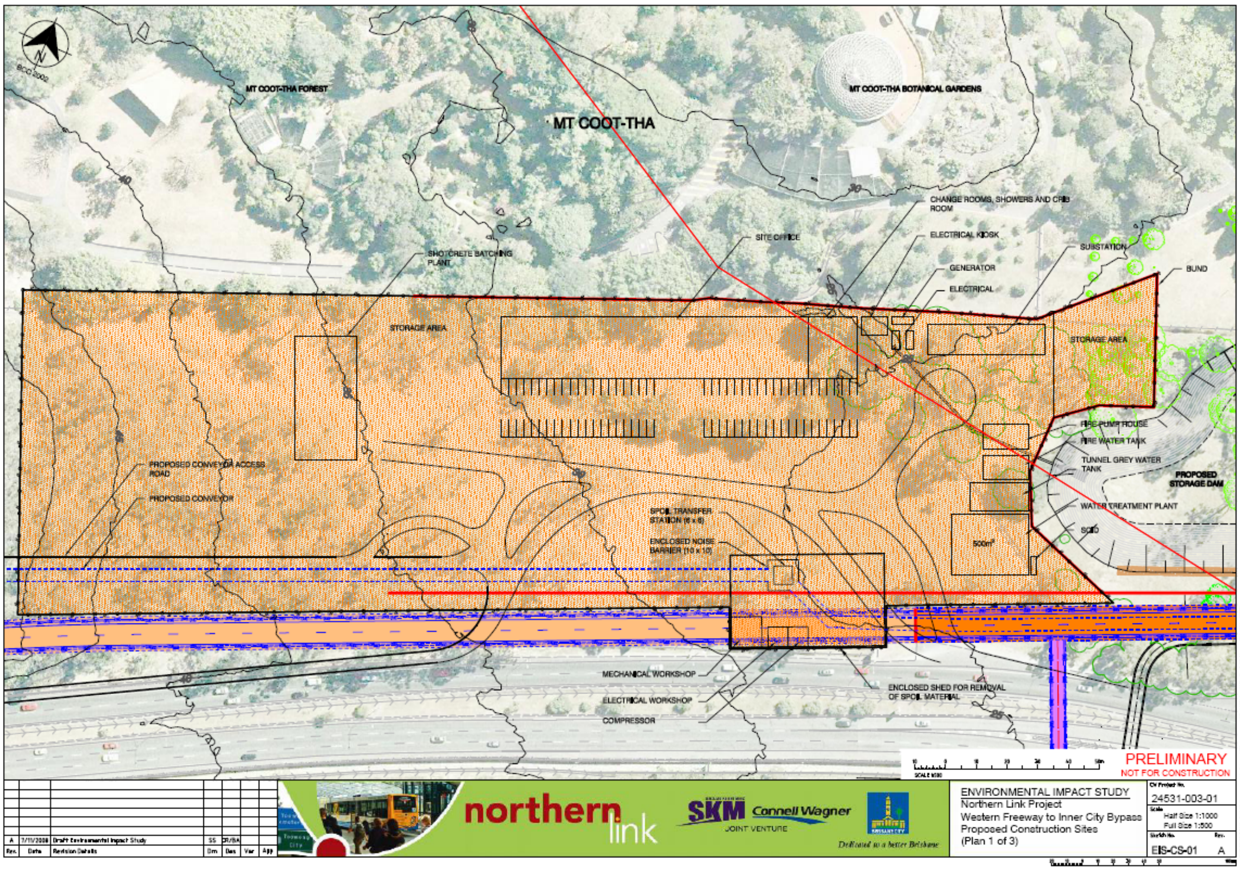
The ambient noise records that have been collected for this project are considered to be representative of the range of ambient noise situations relative to major and minor roads. However, it has not been possible to measure ambient noise levels at all potentially affected locations. Where ambient levels have not been measured for a location of interest, ambient noise levels have been inferred from other measurement locations where it is believed the relative proximity to the major source of ambient noise (ie road traffic) is similar. Where ambient levels have been inferred in this manner, the similar location has been specifically identified in the analysis for reference purposes.

7.2 Western Connection Worksite (WS1)

7.2.1 Proposed Activities

The area for the western connection worksite (WS1) is illustrated in **Figure 8**.

- **Figure 8 Western Connection Worksite (WS1)**



The primary noise-generating activities anticipated during the preparation and operation of the western connection worksite (WS1) are summarised in **Table 29**.

Table 29 Western Connection Worksite Surface Works Noise Sources

Construction Phase and Approx. Duration	Enclosed/Underground Day and Night-time Noise Sources	Additional Daytime Noise Sources
Site Establishment (2 weeks)	Nil	Delivery trucks, excavators, hydraulic rockbreakers, bulldozers, dump trucks, manual trades, compressors, generators
Enclosures Construction (8 weeks)	Nil	Mobile cranes, concrete trucks, concrete pump, delivery trucks, manual trades, excavator, structural steelwork
Works within Enclosure (14 months)	Removal of spoil, supply of temporary support material, ventilation plant, concrete lining of tunnel	Removal of spoil and delivery of materials

7.3 Noise Impacts

7.3.1.1 Site Preparation

Site preparation would involve the installation of safety barriers, initial earthworks to clear the site, delivery of worksite infrastructure and eventually enclosure construction. The noise intensive activities associated with these works would be carried out during the daytime only. It is anticipated that the most noticeable source of noise during site preparation would be earthmoving and rockbreaking during bulk material excavation. In terms of the whole project duration, the site preparation phase is relatively brief.

Noise levels that could be received at representative surrounding buildings during site preparation earthworks are compared with functional internal noise goals for surrounding building uses in **Table 30**.

▪ **Table 30 Noise Assessment – Western Connection Worksite (WS1) - Site Preparation**

		Representative Receptors	
		Residences south of Wool Street	**Residences north of Mt Coot-tha Road**
Minimum Separation from Works (indicative only)		200 m	325 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		2	13
average LAeq,15minute - dBA		52	57
average LAmax,15minute - dBA		67	71
Typical Plant Items	**Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
Bobcat	112	50	46
Dozer	118	56	52
Hydraulic Rockbreaker	120	58	54
35 t, 200 kW Excavator	114	52	48
200 kW Grader	116	54	50
Roller	104	42	38
Compressor 285 L/s	100	38	34
Water Truck	105	43	39
25 t, 200 kW Front-end Loader	116	54	50
25 t Articulated off-road Dump Truck	114	52	48
20 t Mobile Crane	105	43	39
External Noise Goal (LAeq dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with site preparation at the western connection worksite (WS1) are drawn from the assessment summary in **Table 30**.

Residents South of Wool Street

- At the closest residences on the southern side of Wool Street, the highest noise levels arise due to the operation of the rockbreaker and the dozer. Based on "typical" emissions, a marginal exceedance of 3 dBA above the external noise goal is predicted whilst the rockbreaker is in use. Given the limited duration of this particular component of the work it is not likely to result in a significant impact.
- The noise from other plant items will comply with the external design goal.

Residents North of Mt Coot-tha Road

- Site preparation works are predicted to be below the noise goal for the closest residences north of Mt Coot-tha Road.

7.3.1.2 Daytime Tunnelling

During daytime tunnelling operations, the dominant noise sources will be spoil removal via conveyor and deliveries of concrete and other materials. Indicative LAeq(15minutes) noise levels that could be received at representative surrounding buildings during the tunnelling phase are compared with noise goals in **Table 31**.

- **Table 31 Noise Assessment – Western Connection Worksite (WS1) - Daytime Tunnelling**

		Representative Receptors	
		Residences south Wool Street	**Residences north of Mt Coot-tha Road**
Minimum Separation from Works (indicative only)		200 m	325 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		2	13
average $L_{Aeq,15minute}$ - dBA		52	57
average $L_{Amax,15minute}$ - dBA		67	71
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
Concrete Pump	107	45	41
24 t Concrete Truck	112	50	46
Semi Trailer	114	52	48
25 t, 200 kW Front-end Loader	116	54	50
25 t Articulated off-road Dump Truck	114	52	48
Spoil Conveyor[1]	83 per metre	52	50
External Noise Goal (LAeq dBA)		**55**	**55**

1 Predicted using 3-D SoundPLAN model

The following conclusions regarding noise impacts associated with daytime tunnelling works at the western connection are drawn from the assessment summary in **Table 31**.

Residents South of Wool Street and North of Mt Coot-tha Road

- The noise from the plant items are not expected to exceed the design goal at any residence south of Wool Street or north of Mt Coot-tha Road.

7.3.1.3 Night-time Tunnelling

During night-time tunnelling operations, the majority of surface noise sources would be confined within either an enclosure extending over the eastbound tunnel portal and cut and cover sections or entirely within the completed cut and cover structure including closed portal door. Both options would likely achieve a similar acoustic benefit.

Spoil removal would be achieved via conveyor directly to Mt Coot-tha quarry. Construction noise sources would include intermittent dump-truck noise and continuous noise from the temporary tunnel ventilation system.

Indicative LAeq(15minutes) noise levels that could be received at night during the tunnelling phase are compared with noise goals in **Table 32.**

▪ **Table 32 Noise Assessment – Western Connection Worksite (WS1) - Night-time Tunnelling**

		Representative Receptors			
		Residences south Wool Street		Residences north of Mt Coot-tha Road	
Minimum Separation from Works (indicative only)		200 m		325 m	
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		40 (sleeping area, near major roads)		40 (sleeping area, near major roads)	
Internal Sleep Disturbance Noise Goal (LAmax - dBA)		50		50	
Nominal Facade Reduction (dBA)		10		10	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)		**60**		**60**	
Existing Night-Time Levels					
Representative measurement location (external)		2		13	
average LA90, 15minute - dBA		39		43	
average LAeq,15minute - dBA		48		52	
average LAmax,15minute - dBA		60		64	
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor - (dBA)**			
		LAeq	**LAmax**	**LAeq**	**LAmax**
25 t Articulated off-road Dump Truck	114-4=110[1]	48	56	44	52
25 t, 200 kW Front-end Loader	116-4=112[1]	50	58	46	54
Spoil Conveyor[2]	83 per metre	52	55	50	53
Ventilation	Design to meet Background LA90+3 dB at residences	42		46	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)			**60**		**60**

1 Indicates that the effective sound power level has been adjusted for a low performance acoustic enclosure as per corrections in **Table 23**

2 Predicted using 3-D SoundPLAN model

The following conclusions regarding noise impacts associated with night-time tunnelling works at the western connection are drawn from the assessment summary in **Table 32**.

Residents South of Wool Street and North of Mt Coot-tha Road

- The noise from plant items operating during the night-time period at WS1 is not expected to exceed the LAeq(15minutes) or LAmax design goal with the exception of the spoil conveyor which is predicted to marginally exceed the LAeq(15minutes) noise goal. As a result, no significant acoustical impacts would be expected.
- Apart from the detailed design of the enclosure (dedicated structure or enclosed cut and cover), the provision of additional noise mitigation should not be considered for residents at this location.

7.3.2 Noise Mitigation

The following noise control measures are recommended for noise mitigation at the western connection worksite:

- Provide advance notification of the time, type and duration of initial earthworks involved in site preparation.
- Minimise the use of particularly noisy activities such as rockbreaking.

- Ensure the construction of a ‘low’ performance acoustic enclosure over the portal and stockpile or acoustic door entry to completed cut and cover structure is optimised, to ensure there are no ‘leakage paths’ which would degrade the overall performance of the enclosed work area.
- Design of continuously operating ventilation plant and any other plant that operates at night to meet ‘reasonable’ night-time noise objectives as defined in **Section 2.2**.
- The movement of trucks within the worksite should be designed to limit (as much as possible) the need for reversing and therefore reversing alarms. Where issues with reversing alarms occur, consideration should be given to the use of broadband “buzzer” reversing alarms and/or alarms which actively vary their volume according to the ambient noise levels during activation - rather than constant volume (tonal) “beeping” alarms.
- Noise monitoring at the commencement of and periodically during noise intensive activities.

7.3.3 Vibration Impacts

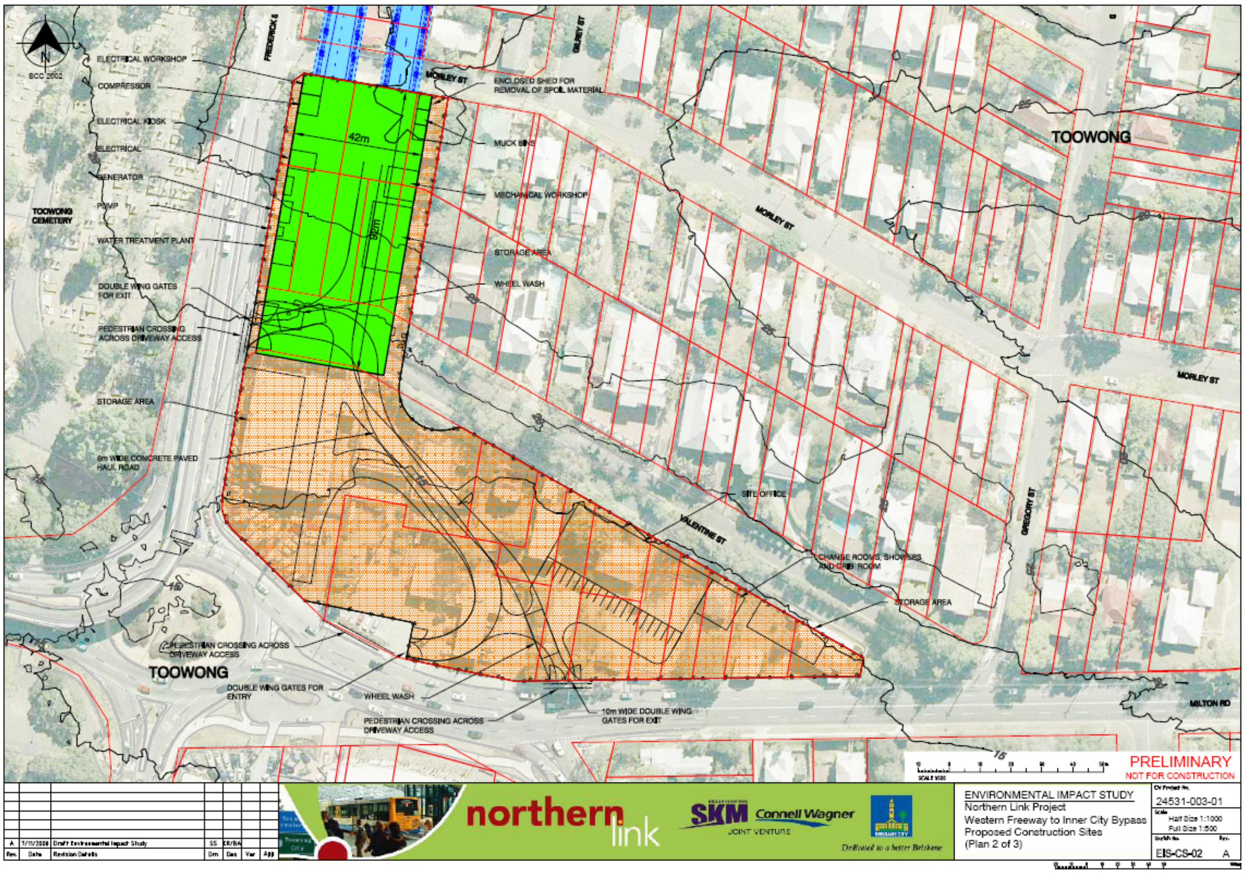
The nearest vibration sensitive location to the western connection worksite (WS1) is the Toowong Cemetery. Likely sources of vibration associated with the construction and operation of the worksite would be rockbreakers and dozers. Due to the separation distances between the majority of the earthworks on the worksite and the cemetery (assuming the proposed storage dam is located adjacent to Mt Coot-tha Road as indicated in **Figure 8**), significant vibration impacts are not anticipated from site preparation and surface activities. Vibration levels associated with the commencement of tunnelling at this worksite are discussed in **Section 10**.

7.4 Toowong Connection Worksite (WS2)

7.4.1 Proposed Activities

The Toowong connection worksite (WS2) is located in the parcel of land between Valentine Street, Frederick Street and Milton Road and is illustrated in **Figure 9**.

Figure 9 Toowong Connection Worksite (WS2)



The primary noise-generating activities anticipated during the preparation and operation of the Toowong connection worksite is summarised in **Table 33**.

Table 33 Toowong Connection Worksite Noise Sources

Construction Phase and Approx. Duration	Enclosed/Underground Day and Night-time Noise Sources	Additional Daytime Noise Sources
Removal of Buildings (2 weeks)	Nil	Excavators, bulldozers, dump trucks, manual trades
Establishment of Site and Enclosure Construction (8 weeks)	Nil	Mobile cranes, concrete trucks, concrete pump, delivery trucks, manual trades, excavator, structural steelwork
Roadheader Tunnelling (25 months)	Dump truck removal of roadheader spoil, supply of temporary support materials, ventilation, supply of concrete for tunnel lining	Removal of spoil and delivery of materials to inside enclosure

Construction of the roadheader launch pit is covered in **Section 8.2**.

7.4.2 Noise Impacts

7.4.2.1 Site Preparation

Site preparation would involve removal of existing buildings, site hoarding and safety barrier installation, delivery of worksite infrastructure and enclosure construction. The noise intensive activities associated with these works would be carried out during the daytime only. It is anticipated that the most noticeable source of noise during site preparation would be heavy earthmoving machinery during demolition and material excavation.

Indicative LAeq(15minutes) noise levels that could be received at representative surrounding buildings during site preparation at the Toowong connection worksite (WS2) are compared with noise goals in **Table 34**.

- **Table 34 Noise Impacts – Toowong Connection Worksite (WS2) - Site Preparation**

		Representative Receptors	
		Residences north of Valentine Street	**Residences South of Milton Road**
Minimum Separation from Works (indicative only)		10 m	20 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		5	4
average LAeq,15minute - dBA		58	68
average LAmax,15minute - dBA		73	79
Typical Plant Items	**Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
Bobcat	112	76	70
Dozer	118	82	76
Hydraulic Rockbreaker	120	84	78
35 t, 200 kW Excavator	114	78	72
Roller	104	68	62
Compressor 285 L/s	100	69	63
Water Truck	105	69	63
25 t, 200 kW Front-end Loader	116	80	74
On-road Truck and Dog	103	67	61
20 t Mobile Crane	105	69	63
Semi Trailer	114	78	72
Concrete Truck	112	76	70
Concrete Pump	107	71	65
External Noise Goal (LAeq dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with site preparation at the Toowong connection worksite (WS2) are drawn from the assessment summary in **Table 34.**

Valentine Street Residences

- The residents in Valentine Street are located as close as 10 m from the worksite as illustrated in **Figure 9**.
- As indicated by the predicted noise levels in **Table 34**, a large number of plant items anticipated to be used at the site during initial works will likely exceed the external design goal during normal

operation. Exceedances of this nature are common when construction works occur in close proximity to receivers.

- It is important that the use of significant noise generating plant be minimised insofar as possible and that nearby residents are notified of the works in advance.

Milton Road Residences

- Significant exceedances (up to 23 dBA) of the daytime noise goals are also predicted for residences along Milton Road.
- For the majority of the short duration construction works required for site preparation, construction noise levels at Milton Road residences will likely be similar in the level or below existing road traffic noise levels from Milton Road.

7.4.2.2 Daytime Tunnelling

During daytime tunnelling works, the dominant noise sources will be associated with spoil removal from the roadheaders and material deliveries to site. Indicative LAeq(15minutes) noise levels that could be received at representative surrounding buildings during daytime tunnelling at the Toowong connection worksite (WS2) are compared with noise goals in **Table 35**.

Table 35 Noise Impacts – Toowong Connection Worksite (WS2) - Daytime Tunnelling

		Representative Receptors	
		Residences north of Valentine Street	**Residences South of Milton Road**
Minimum Separation from Works (indicative only)		10 m	40 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		5	4
average LAeq,15minute - dBA		58	68
average LAmax,15minute - dBA		73	79
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
24 t Concrete Truck	112	76	64
Semi Trailer	114	78	66
On-road Truck and Dog	103	67	55
25 t, 200 kW Front-end Loader	116-19=97[1]	61	55
25 t Articulated off-road Dump Truck	114-19=95[1]	59	53
External Noise Goal (LAeq dBA)		**55**	**55**

1 Indicates that the effective sound power level has been adjusted for a high performance acoustic enclosure as per corrections in **Table 23** with a reduction in performance of 5 dBA associated with open doors.

The following conclusions regarding noise impacts associated with daytime tunnelling works are drawn from the assessment summary in **Table 35**.

Valentine Street Residences

- Due to the close proximity to the tunnel portal and worksite, Valentine Street residences will experience significant construction noise impacts associated with daytime tunnelling activities. Major impacts are associated with heavy vehicles such as concrete and spoil trucks moving on the site.
- As the tunnelling stage of the Toowong connection is anticipated to occur for over two years, consideration of further noise mitigation should be undertaken for this site.
- Further mitigation measures may include:
    - Installation of a temporary noise barrier along the eastern side of the tunnel off ramp adjacent to the Valentine Street cul de sac to reduce heavy vehicle noise near the tunnel portal. The temporary barrier would need to be a minimum of 5 m in height as the adjacent buildings are double storeys. As an alternative, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.
    - Construction of a high performance acoustic enclosure over the portal with indicative acoustic performance as shown in **Table 21** (subject to detailed design).

Milton Road Residences

- Exceedances of the daytime noise design goal are likely to occur for Milton Road residences during periods associated with spoil removal and concrete deliveries to site. Noise levels from these activities are predicted to be below existing road traffic noise levels along Milton Road and therefore are unlikely to result in a significant impact.

7.4.2.3 Night-time Tunnelling

During night-time tunnelling operations at the Toowong connection worksite (WS2), all surface noise sources would be confined within the tunnel portal enclosure. Spoil haul-out and stockpiling would be achieved by loaders and trucks within the enclosure.

Indicative LAeq(15minutes) noise levels that could be received at night during night-time tunnelling for the Toowong connection are compared with noise goals in **Table 36**.

- **Table 36 Noise Impacts – Toowong Connection Worksite (WS2) - Night-time Tunnelling**

		Representative Receptors			
		Residences north of Valentine Street		**Residences South of Milton Road**	
Minimum Separation from Works (indicative only)		10 m		150 m	
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		40 (sleeping areas, near major roads)		40 (sleeping areas, near major roads)	
Internal Sleep Disturbance Noise Goal (LAmax - dBA)		50		50	
Nominal Facade Reduction (dBA)		10		10	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)		**60**		**60**	
Existing Night-Time Levels					
Representative measurement location (external)		5		4	
average LA90, 15minute - dBA		48		41	
average LAeq,15minute - dBA		55		58	
average LAmax,15minute - dBA		68		74	
Typical Plant Items	**Effective Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor - (dBA)**			
		LAeq	**LAmax**	**LAeq**	**LAmax**
25 t Articulated off-road Dump Truck	114-24=90[1]	54	62	30	38
25 t, 200 kW Front-end Loader	116-24=92[1]	56	64	32	40
Ventilation	Design to meet Background LA90+3 dB at residences	51		44	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)			**60**		**60**

1 Indicates that the effective sound power level has been adjusted for a high performance acoustic enclosure as per corrections in **Table 23.**

The following conclusions regarding noise impacts associated with night-time tunnelling works are drawn from the assessment summary in **Table 36**.

Valentine Street Residences

- Due to the close proximity to the tunnel portal and worksite, the nearest Valentine Street residences will experience significant construction noise levels associated with night-time tunnelling activities. A high performance enclosure would be required at this location to reduce the extent of the likely impact. As shown in **Table 36**, night-time noise levels are still predicted to be up to 6 dBA above the recommended goals with a high performance enclosure. This would generally be described as a "noticeable" exceedance. However, when machinery is located further within the tunnel, noise levels will decrease.

Milton Road Residences

- As night-time construction works will occur within the acoustic enclosure at the Toowong worksite, received noise levels from spoil stockpiling works will be below the LAmax and LAeq(15minutes) noise goal.

7.4.3 Noise Mitigation

The following noise control measures may be suitable for noise mitigation at the Toowong connection worksite (WS2):

- Advance notification of the time, type and duration of demolition and initial earthworks.
- Where feasible install (temporary) noise barriers to reduce construction noise during "Site Preparation" and on-site vehicle movements at adjacent property boundaries on Valentine Street. A noise barrier would need to be a minimum of 5 m in height as the adjacent buildings are all double storeys or Queenslanders. As an alternative, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.
- Construction of a high performance acoustic enclosure over the portal and stockpile area with indicative acoustic performance as shown in **Table 21** (subject to detailed design).
- Further assess and consult with property owners immediately adjoining the site as to the best form of noise mitigation, that is noise barriers or the provision of architectural treatment (and ventilation) to impacted rooms facing the worksite to address noise during site preparation and/or rock-drilling at or near the access shaft.
- The movement of trucks within the worksite should be designed to limit (as much as possible) the need for reversing and therefore reversing alarms. Where issues with reversing alarms occur, consideration should be given to the use of broadband "buzzer" reversing alarms and/or alarms which actively vary their volume according to the ambient noise levels during activation - rather than constant volume (tonal) "beeping" alarms.
- Design of continuously operating ventilation plant and any other plant that operates at night to meet 'reasonable' night-time noise objectives as defined in **Section 2.2.2**.
- Noise monitoring at the commencement of and periodically during noise intensive activities.

7.4.4 Vibration Impacts

The anticipated sources of vibration during the site preparation works at WS2 are rockbreaking during demolition works to break up existing slabs and footings and vibratory rolling during earthworks. The bulk of the vibration intensive works will take place beyond 20 m from sensitive receivers and is therefore unlikely to exceed the vibration criteria defined in **Section 2.3**. However it is normal environmental monitoring practice to monitor vibration on structures from vibratory rolling that occurs within a nominal distance of 25 m. This may be relevant for Valentine Street buildings.

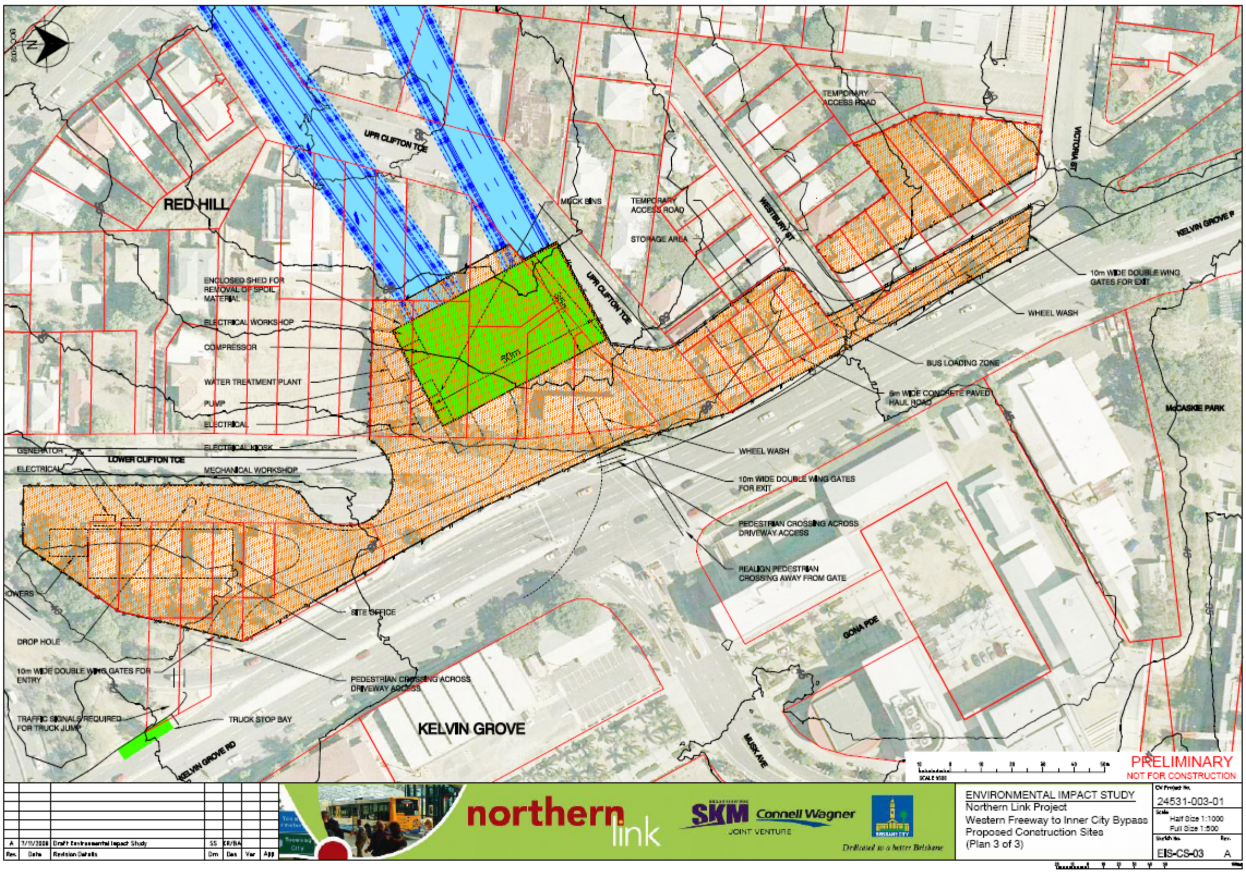
Vibration levels associated with the commencement of tunnelling at this worksite are discussed in **Section 10**.

7.5 Kelvin Grove Connection Worksites (WS3)

7.5.1 Proposed Activities

The location of the Kelvin Grove connection worksite (WS3) is illustrated in **Figure 10**.

- **Figure 10 Kelvin Grove Connection Worksites (WS3)**



The primary noise-generating activities anticipated during the preparation and operation of the Kelvin Grove connection worksites (WS3) are summarised in **Table 37**.

- **Table 37 Kelvin Grove Connection Worksites (WS3) Noise Sources**

Construction Phase and Approx. Duration	Enclosed/Underground Day and Night-time Noise Sources	Additional Daytime Noise Sources
Removal of Buildings (2 weeks)	Nil	Excavators, hydraulic rockbreakers, bulldozers, dump trucks, manual trades, compressors, generators
Establishment of Site and Enclosure Construction x2 (8 weeks for both enclosures)	Nil	Mobile cranes, concrete trucks, concrete pump, delivery trucks, manual trades, excavator, structural steelwork
Roadheader Tunnelling (32 months – Kelvin Grove Rd portal, 15 months – Lower Clifton Tce portal)	Dump truck removal of roadheader spoil, supply of temporary support materials, ventilation, supply of concrete for tunnel lining	Removal of spoil and delivery of materials to inside enclosure

7.5.2 Noise Impacts

7.5.2.1 Site Preparation

Site preparation would involve removal of existing buildings, initial earthworks and enclosure construction. The noise intensive activities associated with these works would be carried out during the daytime only. It is anticipated that the most noticeable source of noise during site preparation would be heavy earthmoving and rockbreaking machinery during the demolition and material excavation stage.

Indicative LAeq(15minutes) noise levels that could be received at representative surrounding buildings during site preparation are compared with noise goals in **Table 38**.

- **Table 38 Noise Impacts – Kelvin Grove Connection Worksites (WS3) - Site Preparation**

		Representative Receptors	
		Residences West of Lower Clifton Terrace	**Residences North of Upper Clifton Terrace**
Minimum Separation from Works (indicative only)		20 m	10 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		9	10
average LAeq,15minute - dBA		65	62
average LAmax,15minute - dBA		80	72
Typical Plant Items	**Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
Bobcat	112	70	76
Dozer	118	76	82
Hydraulic Rockbreaker	120	78	84
35 t, 200 kW Excavator	114	72	78
Roller	104	62	68
Compressor 285 L/s	100	63	69
Water Truck	105	63	69
25 t, 200 kW Front-end Loader	116	74	80
On-road Truck and Dog	103	49	55
20 t Mobile Crane	105	63	69
Semi Trailer	114	72	78
Concrete Truck	112	70	76
Concrete Pump	107	65	71
External Noise Goal (LAeq dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with site preparation at the Kelvin Grove connection worksite (WS3) are drawn from the assessment summary in **Table 38**.

Residents West of Lower Clifton Terrace

- These residents are located approximately 20 m from the tunnel worksite and essentially look down onto the site as the ground rises upwards towards Red Hill.
- At this location the highest noise levels arise due to the rockbreaker. Based on the sound power level for the rock-breaker exceedances of up to 23 dBA are predicted, whilst it is in use. Although existing ambient noise levels are relatively high in this area, predicted construction noise levels would be clearly discernible within dwellings and likely to result in acoustic impacts (eg interference with passive listening, resting, conversation and watching TV).

- Noise mitigation strategies at this site should focus on the use of quietest available plant and construction techniques to establish the site and where possible expediting the early works to allow construction of the acoustic enclosure which will remain in place until tunnelling is complete.

Upper Clifton Terrace and Westbury Street Residences

- These residents are located adjacent to the identified worksite areas including the Kelvin Grove connection portals.
- The close proximity to the works will lead to significant noise impacts as indicated by the predicted noise levels in **Table 38**. Noise levels of this magnitude would be audible within dwellings and likely to result in acoustic impacts.
- The relatively small work area should ensure that the site preparation works are of short duration. Nonetheless the extent of the likely impacts requires consideration of all practicable noise mitigation measures so as to maintain a reasonable noise environment. Noise mitigation options specific to this site are detailed in **Section 7.5.3**.

Kelvin Grove Urban Village / QUT

- Two noise sensitive sites within the this area have been identified:
  - QUT's existing Film and TV Studio – located on the eastern side of QUT and therefore a considerable distance away from the worksite – no construction noise issues are anticipated at this facility
  - QUT's proposed Recording Studio – located in the south western corner of the Kelvin Grove Urban Village – this site is somewhat closer to the worksite but still on the opposite side of Kelvin Grove Rd. No design plans were available at the time of the EIS so it is recommended that a separate specific investigation of construction noise (and vibration) levels be undertaken once plans are available.

7.5.2.2 Daytime Tunnelling

Tunnelling operations at the Kelvin Grove connection worksites (WS3) will be undertaken with multiple roadheaders and the two EPB machines that will be extracted from the Lower Clifton Terrace pit upon completion of the mainline tunnels. Roadheader tunnelling will complete the mainline tunnels between Lower Clifton Terrace and the Inner City Bypass (ICB).

Indicative LAeq(15minutes) noise levels that could be received at representative surrounding buildings during the daytime tunnelling are compared with noise goals in **Table 39**. The predictions assume the adoption of a medium performance acoustic enclosure as described in **Table 23**.

■ **Table 39 Noise Impacts – Kelvin Grove Connection Worksites (WS3) - Daytime Tunnelling**

		Representative Receptors	
		Residences West of Lower Clifton Terrace	**Residences North of Upper Clifton Terrace**
Minimum Separation from Works (indicative only)		20 m	10 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		9	10
average $L_{Aeq,15minute}$ - dBA		65	62
average $L_{Amax,15minute}$ - dBA		80	72
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
24 t Concrete Truck	112	70	76
Semi Trailer	114	72	78
On-road Truck and Dog	103	61	67
25 t, 200 kW Front-end Loader	116-19=97[1]	55	61
25 t Articulated off-road Dump Truck	114-19=95[1]	53	59
External Noise Goal (LAeq dBA)		**55**	**55**

1 Indicates that the effective sound power level has been adjusted for a high performance acoustic enclosure as per corrections in **Table 23** with a reduction in performance of 5 dBA associated with open doors.

The following conclusions regarding noise impacts associated with daytime tunnelling works are drawn from the assessment summary in **Table 39**.

Residents West of Lower Clifton Terrace

- At this location the highest noise levels arise due to the arrival and departure of heavy construction vehicles. It should be noted that this part of the assessment considers construction vehicles on site only whereas impacts associated with vehicles movements on public roads are addressed in **Section 11**.
- Due to the confined worksites at this location, heavy vehicle movements on site would be kept to a minimum. The majority of construction vehicles accessing the site would be truck and dog spoil removal which represent a 6 dBA exceedance of the noise goal.
- As the tunnelling phase of the project will occur for over years, noise mitigation strategies should focus on the use of quietest available plant and construction techniques such as careful design of site access points and vehicle paths to maximise distance to noise sensitive receivers and make use of acoustic enclosures and site buildings to act as screens.

Upper Clifton Terrace and Westbury Street Residences

- Significant acoustic impacts are predicted for residences on Upper Clifton Terrace and Westbury Street.
- On the basis of existing (Year 2007) vehicle movements along Kelvin Grove Road (27,760 southbound and 22,210 northbound – 18 Hour component of AADT) and the predicted maximum vehicle numbers to site (75 to site per day), it is likely that surrounding receivers will associate

Northern Link construction vehicles as part of the normal road network particularly since the worksites are immediately adjacent to Kelvin Grove Road.

7.5.2.3 Night-Time Tunnelling

Indicative LAeq(15minutes) noise levels that could be received at representative residential buildings surround the Kelvin Grove connection worksites (WS3) during the night-time tunnelling are compared with noise goals in **Table 40**. The predictions assume the adoption of a medium performance acoustic enclosure as described in **Table 23**.

- **Table 40 Noise Impacts – Kelvin Grove Connection Worksites (WS3) – Night-Time Tunnelling**

		Representative Receptors			
		Residences West of Lower Clifton Terrace		**Residences North of Upper Clifton Terrace**	
Minimum Separation from Works (indicative only)		20 m		10 m	
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		40 (sleeping areas, near major roads)		40 (sleeping areas, near major roads)	
Internal Sleep Disturbance Noise Goal (LAmax - dBA)		50		50	
Nominal Facade Reduction (dBA)		10		10	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)		**60**		**60**	
Existing Night-Time Levels					
Representative measurement location (external)		9		10	
average LA90, 15minute - dBA		52		41	
average LAeq,15minute - dBA		60		55	
average LAmax,15minute - dBA		73		68	
Typical Plant Items	**Effective Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor - (dBA)**			
		LAeq	**LAmax**	**LAeq**	**LAmax**
25 t Articulated off-road Dump Truck	114-24=90[1]	48	56	54	62
25 t, 200 kW Front-end Loader	116-24=92[1]	50	58	56	64
Ventilation	Design to meet Background LA90+3 dB at residences	55		44	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)			**60**		**60**

1 Indicates that the effective sound power level has been adjusted for a high performance acoustic enclosure as per corrections in **Table 23**.

The following conclusions regarding noise impacts associated with night-time tunnelling works are drawn from the assessment summary in **Table 40**.

Lower Clifton Terrace, Upper Clifton Terrace and Westbury Street Residences

- Due to the close proximity of the surrounding residential receivers to the worksite, a high performance enclosure would be required to significantly reduce the extent of the noise impact, however may still lead to small exceedances (up to 4 dBA) of the night-time noise goal for Upper Clifton Terrace residences.

7.5.3 Noise Mitigation

The following noise control measures are recommended for noise mitigation at the Kelvin Grove connection worksites (WS3):

- Advance notification of the time, type and duration of demolition and initial earthworks.
- Minimise the duration of initial noise intensive site works such as rockbreaking.
- Use of quietest available plant and construction techniques for works occurring in the open environment
- Construction of a high performance acoustic enclosure over the portal with indicative acoustic performance as shown in **Table 21** (subject to detailed design).
- Careful design of the site layout to provide shielding for residences from construction noise. The acoustic enclosure and other site buildings may provide some screening if located between residences and construction plant, particularly for spoil vehicles whilst on site.
- The movement of trucks within the worksite should be designed to limit (as much as possible) the need for reversing and therefore reversing alarms. Where issues with reversing alarms occur, consideration should be given to the use of broadband "buzzer" reversing alarms and/or alarms which actively vary their volume according to the ambient noise levels during activation - rather than constant volume (tonal) "beeping" alarms.
- Design of continuously operating ventilation plant and any other plant that operates at night to meet 'reasonable' night-time noise objectives as defined in **Section 2.2.2**.
- Noise monitoring at the commencement of and periodically during noise intensive activities.

7.5.4 Vibration Impacts

The anticipated sources of vibration during the site preparation works at WS3 are rockbreaking during demolition works to break up existing slabs and footings and vibratory rolling during earthworks (if required). The bulk of the vibration intensive works will take place beyond 20 m from sensitive receivers and is therefore unlikely to exceed the vibration criteria defined in **Section 2.3**. However it is normal environmental monitoring practice to monitor vibration on structures from vibratory rolling that occurs within a nominal distance of 25 m. This would likely be applicable for all adjacent residential receivers.

Four vibration sensitive sites within the Kelvin Grove Urban Village and QUT have been identified:

- QUT's existing Film and TV Studio – located on the eastern side of QUT and therefore a considerable distance away from the worksite – no construction vibration (or regenerated noise) issues are anticipated at this facility
- QUT's proposed Recording Studio – located in the south western corner of the Kelvin Grove Urban Village – this site is somewhat closer to the worksite but still on the opposite side of Kelvin Grove Rd. No design plans were available at the time of the EIS so it is recommended that a separate specific investigation of construction vibration (or regenerated noise) levels be undertaken once plans are available.
- Red Cross Processing Facility – located north of Laboite Theatre and east of McCaskie Park – this site is a considerable distance from the worksite but one piece of vibration sensitive equipment has been identified. At the time of the EIS, some preliminary "measurement" specifications had been received from the Red Cross but no "limit/criterion" specification was available. Therefore, an

assessment of construction vibration is recommended to be undertaken at a later stage when further information is available.

- QUT's Institute of Health and Biomedical Innovation – located directly north of the Red Cross facility - No information in relation to the specific vibration sensitive equipment within this facility had been supplied by QUT at the time of the EIS so it is recommended that a separate specific investigation of construction vibration levels be undertaken if specific items of equipment are identified as vibration sensitive.

Vibration levels associated with the commencement of tunnelling at this worksite are discussed in **Section 10**.

8. Surface Construction of Roadways

8.1 Western Freeway Connection

8.1.1 Proposed Activities

The primary noise-generating activities anticipated during the construction of the western surface connection roads, interfacing with the Western Freeway, are summarised in **Table 41**.

Table 41 Western Surface Road Connections - Construction Noise Sources

Construction Phase (and Approx Duration)	Night-time Noise Sources	Additional Daytime Noise Sources
Earthworks (4 months)	Nil	Excavators bulldozers, graders, loaders, bobcats, compaction equipment, dump trucks, water trucks, manual trades
Cut and Cover Construction (9 months)	Nil	Bored piling rig, hydraulic rockbreakers, rock ripping equipment, pneumatic jack hammer, excavators, shotcrete equipment, rock bolting equipment, compressors, cranes, concrete pump
Transition Structure Construction (12 months)	Nil	Bored piling rig, hydraulic rockbreakers, rock ripping equipment, pneumatic jack hammer, excavators, shotcrete equipment, rock bolting equipment, compressors, cranes, concrete pump
New Road Construction and Existing Road Re-surfacing (4 months)	As for daytime but limited to areas of interface with existing Western Freeway road infrastructure	Delivery trucks, paving machine, compaction equipment, line marking

8.1.2 Noise Impacts

Construction of surface road connections would generally be confined to daytime hours except for the connection work with and realignment of the Western Freeway. It is anticipated that the highest daytime noise levels at residential locations due to Northern Link construction would typically result from the cut and cover and transition structure excavation works. The highest night-time noise levels are likely to be from Western Freeway realignment works. The following sections predict the likely noise levels at the nearest receivers to the Northern Link surface road connection works.

8.1.2.1 Night-time Western Freeway Road Works

Indicative noise levels that could be received at the nearest residential receivers during the night-time Western Freeway road works are compared with noise goals in **Table 42**.

- **Table 42 Noise Impacts - Western Connection Surface Road Construction – Night-time Works**

		Representative Receptors			
		Residences south Wool Street		**Residences north of Mt Coot-tha Road**	
Minimum Separation from Works (indicative only)		120 m		400 m	
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		40 (sleeping area, near major roads)		40 (sleeping area, near major roads)	
Internal Sleep Disturbance Noise Goal (LAmax - dBA)		50		50	
Nominal Facade Reduction (dBA)		10		10	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)		**60**		**60**	
Existing Night-Time Levels					
Representative measurement location (external)		2		13	
average LA90, 15minute - dBA		39		43	
average LAeq,15minute - dBA		48		52	
average LAmax,15minute - dBA		60		64	
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor - (dBA)**			
		LAeq	**LAmax**	**LAeq**	**LAmax**
Asphalt Paver	114	56	64	46	54
Semi Trailer	114	56	64	46	54
Roller	104	46	54	36	44
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)			**60**		**60**

The following conclusions regarding noise impacts associated with night-time surface road works at the western connection are drawn from the assessment summary in **Table 42**.

Residents South of Wool Street

- At the closest residences to the south of Wool Street, the highest noise levels arise due to the operation of the asphalt paver and delivery truck. Based on "typical" emissions, an exceedance of 4 dBA above the external LAmax noise goal is predicted whilst road resurfacing works are taking place. The predicted construction noise levels in **Table 42** are based on a worst case scenario when the plant are operating at the closest point to the receiver and do not take into consideration effects from topography. Construction noise levels may be at least 5 dBA lower if line of sight is broken due to topography or other buildings which may be the case for some Wool Street receivers.
- The noise from other plant items will comply with the external noise design goals.

Residents North of Mt Coot-tha Road

- Night-time Northern Link road construction works are predicted be below the noise design goals at the closest residences north of Mt Coot-tha Road.

8.1.2.2 Daytime Surface Connection Works

Indicative noise levels that could be received at representative surrounding buildings during daytime cut and cover and transition structure construction are compared with noise goals in **Table 43**.

Table 43 Noise Impacts – Western Connection Surface Road Construction – Daytime Works

		Representative Receptors	
		Residences south of Wool Street	Residences north of Mt Coot-tha Road
Minimum Separation from Works (indicative only)		120 m	400 m
AS/NZS 2107 Maximum Internal Noise Goal (L_{Aeq} - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (L_{Aeq} dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		2	13
average $L_{Aeq,15minute}$ - dBA		52	57
average $L_{Amax,15minute}$ - dBA		67	71
Typical Plant Items	**Effective Sound Power Level (L_{Amax} dBA)**	**Indicative External Plant Noise Level at Receptor (L_{Aeq} dBA)**	
Hydraulic Rockbreaker	120	62	52
35 t, 200 kW Excavator	114	56	46
Compressor 285 L/s	100	47	37
Water Truck	105	47	37
100 Tonne Hydraulic Crane	110	52	42
Bored piling rig	118	60	50
Pneumatic Rock Drill	120	62	52
Concrete Pump	107	49	39
24 t Concrete Mixer	112	54	44
External Noise Goal (L_{Aeq} dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with daytime surface road works at the western connection are drawn from the assessment summary in **Table 43**.

Residents South of Wool Street

- At the closest residences to the south of Wool Street, the highest noise levels arise due to the operation of the rockbreaker and rock drill. These items of plant are typically used on an intermittent basis and will likely be used below existing ground level (ie within the cut) therefore creating a barrier effect on noise emissions from the site. This is particularly the case during the latter stages of the cut and cover and transition construction works.
- Other plant items such as bored piling rigs and excavators will be required to operate over many months and as indicated in **Table 43** may have the potential to result in an acoustic impact (ie audible inside dwellings) for residences to the south of the Western Freeway.
- It is recommended that noise monitoring be carried out at the commencement of bored piling works to confirm received construction noise levels to identify if further noise mitigation is required such as localised acoustic screens.

Residents North of Mt Coot-tha Road

- At the closest residences north of Mt Coot-tha Road, surface road construction works are predicted to comply with the nominated noise goal.

8.1.3 Noise Mitigation

The following noise control measures are recommended for noise mitigation during surface road construction:

- Advance notification of the time, type and duration of noise intensive construction activities, particularly for night-time works.
- Selection of quietest available construction plant and techniques to keep noise emissions to a minimum.
- Location of plant items to maximise distance to noise sensitive receivers.
- Attended noise measurements at the commencement of long-term noise intensive construction works to identify the need for additional noise mitigation measures.
- Where feasible, erect temporary acoustic screens to mitigate noise from rockbreaking.
- Noise monitoring at the commencement of and periodically during noise intensive activities.

8.1.4 Vibration Impacts

The anticipated sources of vibration during the construction of the western surface connection roads are vibratory rolling during the existing road (Western Freeway and Mt Coot-tha Road) realignment works and rockbreaking during cut and cover and transition structure construction. The majority of these works will take place far enough away from vibration sensitive receivers to avoid any impact.

Rockbreaking may be required at the TBM launch pits located adjacent to the Toowong Cemetery. If the works are required to take place within 10 m of grave sites then vibration monitoring should be carried out to ensure vibration levels do not exceed the 2 mm/s goal listed in **Table 5**.

8.2 Toowong Connection

8.2.1 Proposed Activities

The primary noise-generating activities anticipated during the construction of the Toowong surface connections are summarised in **Table 44**.

Table 44 Toowong Surface Connections - Construction Noise Sources

Construction Phase and Approx. Duration	Night-time Noise Sources	Daytime Noise Sources
Removal of buildings (2 months)	Nil	Excavators, hydraulic breakers, bulldozers, dump trucks, manual trades, compressors, generators
Earthworks (8 months)	Nil	Excavators, bulldozers, graders, loaders, bobcats, compaction equipment, dump trucks, water trucks, manual trades
Cut and cover Construction (3 months)	Nil	Bored piling rig, excavators, rockbreakers, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Elevated structures (4 and 8 months)	As for daytime but limited to areas where works are required on or over Milton Road.	Bored piling rig, excavators, steel fixing, compressors, crane, concrete pump
Road surfacing for first stage traffic diversion (7 months)	As for daytime but limited to areas of interface with existing road infrastructure.	Delivery trucks, paving machine, compaction equipment, line marking
Road surfacing for final traffic arrangement (5 months)	As for daytime but limited to areas of interface with existing road infrastructure.	Delivery trucks, paving machine, compaction equipment, line marking

8.2.2 Noise Impacts

Where possible, construction of surface road connections at Toowong would be confined to daytime hours. **Table 44** does however show that some critical stages of the project are required to be carried out at night-time primarily for public safety and the need to divert traffic on Milton Road during periods of minimal traffic to allow construction within the existing road corridor to occur.

It is anticipated that the highest daytime noise levels at residential locations due to Northern Link construction would typically result from construction of the cut and cover area and elevated structures adjacent to Milton Road.

The highest anticipated night-time noise levels would be due to construction of the elevated structures over Milton Road and road realignment and re-surfacing works. As the equipment list for the elevated structure and cut and cover construction are very similar, the predicted noise levels due to each activity will be very similar. Therefore, these activities have been combined into a single assessment of the likely noise impacts for the daytime period.

8.2.2.1 Night-time Construction of Toowong Connection Elevated Structures

Indicative noise levels that could be received at representative surrounding buildings during night-time elevated structure construction are compared with noise goals in **Table 45**.

■ **Table 45 Noise Impacts – Toowong Elevated Structures – Night-time Works**

		Representative Receptors			
		Residences north of Valentine Street		Residences South of Milton Road	
Minimum Separation from Works (indicative only)		60 m		20 m	
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		40 (sleeping areas, near major roads)		40 (sleeping areas, near major roads)	
Internal Sleep Disturbance Noise Goal (LAmax - dBA)		50		50	
Nominal Facade Reduction (dBA)		10		10	
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)		**60**		**60**	
Existing Night-Time Levels					
Representative measurement location (external)		5		4	
average LA90, 15minute - dBA		48		41	
average LAeq,15minute - dBA		55		58	
average LAmax,15minute - dBA		68		74	
Typical Plant Items	**Effective Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor - (dBA)**			
		LAeq	**LAmax**	**LAeq**	**LAmax**
100 Tonne Hydraulic Crane	110	58	66	68	76
Flat Bed Truck	114	62	70	72	80
Compressor 285 L/s	100	48	56	58	66
Concrete Truck	112	60	68	70	78
Concrete Pump	107	55	63	65	73
External Noise Goal (LAeq dBA)		**50**		**50**	
External Noise Goal (LAmax dBA)			**60**		**60**

The following conclusions regarding noise impacts associated with night-time surface road works at Toowong are drawn from the assessment summary in **Table 45**.

Residences on Valentine Street and South of Milton Road

- **Table 45** shows that the noise levels for residences surrounding the Northern Link elevated structures construction would likely be found intrusive (up to 22 dBA above the $L_{Aeq(15minutes)}$ noise goals). Additionally, exceedances of 20 dBA above the L_{Amax} noise goal are predicted. This level of intrusion would interfere with normal indoor living (eg interference with passive listening, resting and conversation) and could cause sleep disturbance. Consequently, it is necessary that all reasonable and feasible noise mitigation be examined so as to maintain a reasonable noise environment at these residences during the construction works.
- It should be noted that whilst the road structure under construction is elevated above Milton Road, the majority of the noise intensive plant required to complete the works will be positioned on or adjacent to Milton Road. This provides an opportunity for construction plant to be located behind approach ramps or safety barriers/hoarding etc, to both maximise distance to receivers as well as create a barrier effect and reduce the likely impact.

- If modification to the process is ineffective, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.

8.2.2.2 Daytime Surface Connection Works

Indicative noise levels that could be received at the most exposed buildings during daytime earthworks, elevated structure and cut and cover construction are compared with noise goals in **Table 46**.

Table 46 Noise Impacts – Toowong Surface Construction – Daytime Works

		Representative Receptors	
		Residences north of Valentine Street	**Residences South of Milton Road**
Minimum Separation from Works (indicative only)		10 m	10 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		5	4
average $L_{Aeq,15minute}$ - dBA		58	68
average $L_{Amax,15minute}$ - dBA		73	79
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
Hydraulic Rockbreaker	120	84	84
35 t, 200 kW Excavator	114	78	78
38 t, 250 kW Dozer	118	82	82
Compressor 285 L/s	100	64	64
Water Truck	105	69	69
100 Tonne Hydraulic Crane	110	74	74
Bored piling rig	118	82	82
Pneumatic Rock Drill	120	84	84
Concrete Pump	107	71	71
24 t Concrete Mixer	112	76	76
200 kW Grader	116	80	80
External Noise Goal (LAeq dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with daytime surface road works at Toowong are drawn from the assessment summary in **Table 46**.

Residences on Valentine Street and South of Milton Road

- **Table 45** shows that the noise levels for residences surrounding the Northern Link earthworks, elevated structures and cut and cover construction would likely be found intrusive (up to 29 dBA above the LAeq(15minutes) noise goals). This level of intrusion would interfere with normal indoor living (eg interference with passive listening, resting and conversation) and could cause sleep disturbance. Consequently, it is necessary that all reasonable and feasible noise mitigation be examined so as to maintain a reasonable noise environment at these residences during the construction works. The temporary noise barrier around the Toowong cut and cover site discussed in **Section 7.4.2.2** would also provide a reduction in construction noise levels during the cut and cover works.

8.2.3 Noise Mitigation

The following noise control measures are recommended for mitigation of noise around the Toowong surface connection works, guided by the 'reasonable' noise objectives for construction noise as defined in **Section 2.2.2**.

- Construction of temporary noise barriers between the cut and cover work area and Valentine Street residences to reduce construction noise for receivers to the east and north of the site.
- Advance notification of the time, type and duration of noise intensive works, such as bored piling, particularly where required immediately adjacent to residential receivers or at night-time.
- Selection of quietest available construction plant and techniques to keep noise emissions to a minimum.
- Assist owners of properties nearest the construction site to temporarily upgrade the acoustic insulation and ventilation of rooms facing the site.
- Location of plant items to maximise distance to noise sensitive receivers.
- Attended noise measurements at the commencement of and periodically for noise intensive construction works to identify the need for additional noise mitigation measures.
- Early construction of the operational noise barriers north and south of Milton Road to protect residences during the construction period.

8.2.4 Vibration Impacts

The anticipated sources of vibration during the construction of the Toowong surface connection roads are vibratory rolling during the road realignment works and rockbreaking during cut and cover and transition structure construction. Some of this work will take place in close proximity (less than 25 m) from vibration sensitive receivers presenting potential impacts. Therefore it is important that nearby receivers are notified in advance of the vibration intensive works and that monitoring be carried out at the commencement of the works to confirm the levels are below the criteria nominated in **Section 2.3**.

8.3 Kelvin Grove Road Connection

8.3.1 Proposed Activities

The primary noise-generating activities anticipated during the construction of the Kelvin Grove Road surface connections are summarised in **Table 47**.

▪ **Table 47 Kelvin Grove Road Surface Connections - Construction Noise Sources**

Construction Phase and Approx Duration	Night-time Noise Sources	Daytime Noise Sources
Removal of buildings (1 month)	Nil	Excavators, hydraulic breakers, bulldozers, dump trucks, manual trades, compressors, generators
Earthworks (2 months)	Nil	Excavators, hydraulic breakers, bulldozers, dump trucks, manual trades, compressors, generators
Cut and cover construction (15 months)	Bored piling. excavators, steel fixing, lifting precast items, concreting equipment and road surfacing	Bored piling rig, excavators, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Road surfacing for first stage traffic diversion (7 months)	As for daytime but limited to areas of interface with existing Sandgate Rd	Bored piling rig, excavators, steel fixing, compressors, crane, concrete pump
Road surfacing for final traffic arrangement (7 months)	As for daytime but limited to areas of interface with existing road infrastructure (Sandgate Rd and East West Arterial)	Delivery trucks, paving machine, compaction equipment, line marking

8.3.2 Noise Impacts

Construction noise levels will be limited to daytime hours except areas interfacing with the existing road infrastructure along Kelvin Grove Road. It is anticipated that the highest noise levels would typically result from the cut and cover construction and road resurfacing of Kelvin Grove Road.

8.3.2.1 Daytime Construction of Kelvin Grove Road Cut and Cover Structures

Indicative noise levels that could be received at the most exposed residences during daytime construction of cut and cover areas adjacent to Kelvin Grove Road are compared with noise goals in **Table 48**.

Table 48 Noise Impacts – Kelvin Grove Road Construction - Daytime Road works

		Representative Receptors	
		Residences West of Lower Clifton Terrace	**Residences North of Upper Clifton Terrace**
Minimum Separation from Works (indicative only)		60 m	25 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (living area, near major roads)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		9	10
average LAeq,15minute - dBA		65	62
average LAmax,15minute - dBA		80	72
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
35 t, 200 kW Excavator	114	62	70
Compressor 285 L/s	100	53	61
100 Tonne Hydraulic Crane	110	58	66
Bored piling rig	118	66	74
Pneumatic Rock Drill	120	68	76
Concrete Pump	107	55	63
24 t Concrete Mixer	112	60	68
Asphalt Paver	114	62	70
Semi Trailer	114	62	70
Roller	104	52	60
External Noise Goal (LAeq dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with daytime surface road works at Toowong are drawn from the assessment summary in **Table 48**.

Lower Clifton Terrace, Upper Clifton Terrace and Westbury Street Residences

- For residential locations west of Kelvin Grove Road, the predicted daytime LAeq(15minutes) noise levels from the cut and cover construction works are up to 21 dBA higher than the desired noise goals. This would be found to be intrusive and this level of intrusion would result in an acoustic impact on the residences.

8.3.2.2 Noise Mitigation

The following noise control measures are recommended for mitigation of Northern Link construction noise around surface road works for the Kelvin Grove connections, guided by the 'reasonable' noise objectives for construction noise as defined in **Section 2.2.2**.

- Advance notification of the time, type and duration of works, especially night-time works.
- Where possible, select construction processes and plant to minimise construction noise.
- If required, assist owners of properties nearest the construction site to temporarily upgrade the acoustical insulation and ventilation of rooms facing the construction area.
- Noise monitoring at the commencement of and periodically during noise intensive activities.

- Early construction of the operational noise barriers west of Kelvin Grove Road to protect residences during the construction period, or erect temporary construction noise barriers in a similar location.

8.3.2.3 Vibration Impacts

The bulk of the vibration intensive works, anticipated to be excavation of material and compaction for new road construction, at the Kelvin Grove Road connection will take place beyond 20 m from sensitive receivers and is therefore unlikely to exceed the vibration goals defined in **Section 2.3**.

However it is normal environmental monitoring practice to monitor vibration on structures from vibratory rolling that occurs within a nominal distance of 25 m. This would likely be applicable for all adjacent residential receivers in Upper Clifton Terrace and Westbury Street.

8.4 ICB Connection

8.4.1 Proposed Activities

The primary noise-generating activities anticipated during the construction of the ICB connection is summarised in **Table 49**.

Table 49 ICB Surface Connection - Construction Noise Sources

Construction Phase and Approx Duration	Night-time Noise Sources	Daytime Noise Sources
Cut and cover construction (19 months)	Bored piling. excavators, steel fixing, lifting precast items, concreting equipment and road surfacing	Bored piling rig, excavators, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Transition structure construction (22 months)	Nil	Bored piling rig, excavators, shotcrete equipment, rock bolting equipment, compressors, lifting (crane) for precast items, concrete pump, ventilation equipment
Road surfacing (4 months)	As for daytime but limited to areas of interface with existing ICB infrastructure	Delivery trucks, paving machine, compaction equipment, line marking

8.4.2 Noise Impacts

All construction noise levels will be limited to daytime construction except areas interfacing with existing ICB infrastructure and associated road realignment works. It is anticipated that highest noise levels would typically result from cut and cover and transition structure construction south of Normanby Terrace.

8.4.2.1 Night-time Construction of Cut and Cover Structures for ICB Connection

Indicative noise levels that could be received at the most exposed residences during night-time cut and cover construction at the ICB interface are compared with noise goals in **Table 50**.

- **Table 50 Noise Impacts – ICB Connection Construction – Night-time Works**

		Representative Receptors	
		Normanby Terrace and Victoria Park Road Residences[1]	
Minimum Separation from Works (indicative only)		50 m	
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		40 (sleeping area, near major roads)	
Internal Sleep Disturbance Noise Goal (LAmax - dBA)		50	
Nominal Facade Reduction (dBA)		10	
External Noise Goal (LAeq dBA)		**50**	
External Noise Goal (LAmax dBA)		**60**	
Existing Night-Time Levels			
Representative measurement location (external)		12	
average LA90, 15minute - dBA		47	
average LAeq,15minute - dBA		54	
average LAmax,15minute - dBA		64	
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor - (dBA)**	
		LAeq	**LAmax**
35 t, 200 kW Excavator	114	59	67
Compressor 285 L/s	100	50	53
100 Tonne Hydraulic Crane	110	55	63
Bored piling rig	118	63	71
Concrete Pump	107	52	60
24 t Concrete Mixer	112	57	65
Asphalt Paver	114	59	67
Semi Trailer	114	59	67
Roller	104	49	57
External Noise Goal (LAeq dBA)		**50**	
External Noise Goal (LAmax dBA)			**60**

1 A 5 dBA reduction has been assumed for these residences due to the existing ICB noise barrier.

The following conclusions regarding noise impacts associated with night-time surface road works at the ICB connection are drawn from the assessment summary in **Table 50**.

Normanby Terrace and Victoria Park Road Residences

- For Normanby Terrace and Victoria Park Road residences, the predicted LAeq(15minutes) and LAmax noise levels from the cut and cover construction works are up to 13 dBA and 11 dBA higher than the respective noise goals. During the night-time period, this would likely be found to be intrusive and possibly result in sleep disturbance at the nearest residences. It is likely that for some construction noise sources actual levels will be lower due to a greater barrier effect than the 5 dBA (broken line of sight) reduction applied to the results in **Table 50**.
- On the basis of the predicted noise goal exceedances, it will be important to notify residents well in advance of all noise intensive night-time construction works.
- Insofar as possible, the majority of the construction works required to complete the ICB connection should be carried out during the daytime period so as to avoid sleep disturbance.

8.4.2.2 Daytime Construction of Cut and Cover Structures for ICB Connection

Indicative noise levels that could be received at the most exposed residences during the daytime construction works at the ICB connection are compared with noise goals in **Table 51**.

- **Table 51 Noise Impacts – ICB Connection Construction - Daytime works**

		Representative Receptors		
		Normanby Tce & Victoria Park Rd Residences[1]	Brisbane Grammar School (Indoor Sports Centre)	Brisbane Girls Grammar School (Classrooms)
Minimum Separation from Works (indicative only)		25 m	100 m	70 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living areas, near major roads)	45 (school teaching area)	45 (school teaching area)
Nominal Facade Reduction (dBA)		10	10	10
External Noise Goal (LAeq dBA)		**55**	**55**	**55**
Existing Daytime Levels				
Representative measurement location (external)		12	11	12
average LAeq,15minute - dBA		58	63	58
average LAmax,15minute - dBA		68	78	68
Typical Plant Items	**Plant Sound Power Levels (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**		
35 t, 200 kW Excavator	114	65	58	61
Compressor 285 L/s	100	56	49	52
Water Truck	105	56	49	52
100 Tonne Hydraulic Crane	110	61	54	57
Bored piling rig	118	69	62	65
Pneumatic Rock Drill	120	71	64	67
Concrete Pump	107	58	51	54
24 t Concrete Mixer	112	63	56	59
Asphalt Paver	114	65	58	61
Semi Trailer	114	65	58	61
Roller	104	55	48	51
External Noise Goal (LAeq dBA)		**55**	**55**	**55**

1 A 5 dBA reduction has been assumed for these residences due to the existing ICB noise barrier.

The following conclusions regarding noise impacts associated with daytime surface road works at the ICB connection are drawn from the assessment summary in **Table 51**.

Normanby Terrace and Victoria Park Road Residences

- For Normanby Terrace and Victoria Park Road residences, the predicted LAeq(15minutes) noise levels from the cut and cover construction works are up to 16 dBA above the noise goal. It is likely that an exceedance of this magnitude would be found to be intrusive and possibly interfere with indoor amenity. It is likely that for some construction noise sources actual levels will be lower due to a greater barrier effect than the 5 dBA (broken line of sight) reduction applied to the results in **Table 51**.

Brisbane Grammar School (Indoor Sports Centre)

- The highest Northern Link construction noise levels at Brisbane Grammar School are predicted to result during use of the rock drill and bored piling rig. Other construction noise sources are similar in level to existing ambient noise, primarily from the ICB, for this area.

Brisbane Girls Grammar School (Classrooms)

- The highest Northern Link construction noise levels at Brisbane Girls Grammar School are predicted to result during use of the rock drill. An exceedance of 12 dBA above the external noise goal is predicted during its use. Levels of this magnitude would be audible within classrooms and may interfere with internal activities. Further investigation of the attenuation through the façade of the school buildings closest to the construction works is recommended to further assess and mitigate noise impacts.

8.4.3 Noise Mitigation

The following noise control measures are recommended for mitigation of noise from the ICB connection construction works, guided by the 'reasonable' noise objectives for daytime construction noise as defined in **Section 2.2.2**.

- Advance notification of the time and duration of works, especially any night works.
- Select construction processes and plant to minimise construction noise.
- Assist owners of properties nearest the construction site to temporarily upgrade the acoustical insulation and ventilation of rooms facing the construction area.
- A detailed investigation of classroom facades at Brisbane Grammar and Brisbane Girls Grammar Schools to determine actual noise attenuation and therefore assess the need for further mitigation.
- Early construction of the operational noise barriers to protect Normanby Terrace residences during the construction period, or erect temporary construction noise barriers in a similar location.

8.4.4 Vibration Impacts

It is not anticipated that vibration levels associated with vibratory rolling during road surfacing of the Northern Link ICB connection will be significant. However it is normal environmental monitoring practice to monitor vibration on structures during vibratory rolling that occurs within a nominal distance of 25 m. This may be relevant for properties in Normanby Terrace and Victoria Park Road that would be nearest to works on the northern side of the ICB.

9. Ventilation Infrastructure Construction

9.1 Western Outlet

The western outlet point requires a ventilation tunnel approximately 45 m^2 to be constructed from the cut and cover section of the westbound tunnel to the outlet location and a 20 m^2 connection to the eastbound tunnel smoke extract duct. Due to the proximity of the Western Freeway, there is limited opportunity to locate the ventilation station within the upper part of the cut and cover tunnel. Therefore the western ventilation outlet would likely be located adjacent to the Northern Link tunnel or transition structure at the Western Freeway.

Construction of the western ventilation outlet would be similar to the cut and cover tunnel construction activities and provided the outlet is located close to the Northern Link mainline tunnel impacts associated with these works would be similar in nature (refer to **Section 8.1.2.2** for indicative impacts). For this reason no further assessment is required.

It is anticipated that these works would coincide with the cut and cover and transition structure construction.

9.2 Eastern Connection

The eastern outlet point requires a ventilation tunnel approximately 45 m^2 to be constructed from the cut and cover section of the eastbound tunnel to the outlet location and a 20 m^2 connection to the westbound tunnel smoke extract duct.

Construction of the eastern ventilation outlet would likely require a combination of driven tunnel (roadheader) near the extraction point and cut and cover close to the outlet point. Daytime construction noise levels have been predicted for the Victoria Park Golf Course ventilation outlet and are presented in **Table 52**.

- **Table 52 Noise Impacts – Eastern Ventilation Station Construction - Daytime Works**

		Representative Receptors	
		Victoria Park Road Residences	**QUT Kelvin Grove Campus**
Minimum Separation from Works (indicative only)		20 m	200 m
AS/NZS 2107 Maximum Internal Noise Goal (LAeq - dBA)		45 (living area, near major roads)	45 (university teaching area)
Nominal Facade Reduction (dBA)		10	10
External Noise Goal (LAeq dBA)		**55**	**55**
Existing Daytime Levels			
Representative measurement location (external)		12	14
average LAeq,15minute - dBA		58	54
average LAmax,15minute - dBA		68	68
Typical Plant Items	**Effective Sound Power Level (LAmax dBA)**	**Indicative External Plant Noise Level at Receptor (LAeq dBA)**	
35 t, 200 kW Excavator	114	72	52
Compressor 285 L/s	100	58	38
20 Tonne Mobile Crane	105	63	43
Bored piling rig	118	76	56
Pneumatic Rock Drill	120	78	58
Concrete Pump	107	65	45
24 t Concrete Mixer	112	70	50
Semi Trailer	114	72	52
External Noise Goal (LAeq dBA)		**55**	**55**

The following conclusions regarding noise impacts associated with ventilation station construction works are drawn from the assessment summary in **Table 52**.

Victoria Park Road Residences

- The residents in Victoria Park Road will at times be located as close as 20 m from ventilation tunnel construction. As the works progress towards the outlet point this separation distance will increase to beyond 200 m.
- As indicated by the predicted noise levels in **Table 52**, a large number of plant items required to carry out the works will likely exceed the external design goal during normal operation at the site. Exceedances of this nature are common when construction works occur in close proximity to receivers.
- It is important that the use of significant noise generating plant be minimised insofar as possible and that nearby residents are notified of the works in advance.

QUT Kelvin Grove Campus

- The highest construction noise levels at QUT are predicted to exceed the noise goal by a marginal 3 dBA. Levels of this magnitude are unlikely to be "intrusive" within classrooms. It was noted during the noise monitoring site visit that the nearest row of buildings to the proposed outlet site were not teaching areas.

9.2.1 Noise Mitigation

The following noise control measures are recommended for mitigation of potential noise from ventilation station construction works, guided by the 'reasonable' noise objectives for daytime construction noise as defined in **Section 2.2.2**.

- Advance notification of the time, type and duration of works, especially any night works in the case of residential receivers.
- Select construction processes and plant to minimise construction noise.

9.2.2 Vibration Impacts

It is not anticipated that vibration levels associated with the eastern ventilation station construction will result in vibration impacts. However it is normal environmental monitoring practice to monitor vibration on structures during vibratory rolling that occurs within a nominal distance of 25 m.

10. Tunnelling Between Portals

10.1 Introduction

It is proposed that two Tunnel Boring Machines (TBM) will be used to excavate the mainline tunnel section between the Western Freeway launch pits to the ICB extraction pit. Roadheader and drill-and-blast excavation is likely to be used at the following locations:

- Toowong ramp connections including Frederick Street and Milton Road Y Junctions.
- Kelvin Grove Road ramp connection tunnels including the Kelvin Grove Road Y Junctions.
- Cross passages, low point sumps, substations etc.

Vibration issues have been considered in relation to residential properties, aged-care facilities, educational facilities, sensitive commercial facilities and known buildings of particular heritage value.

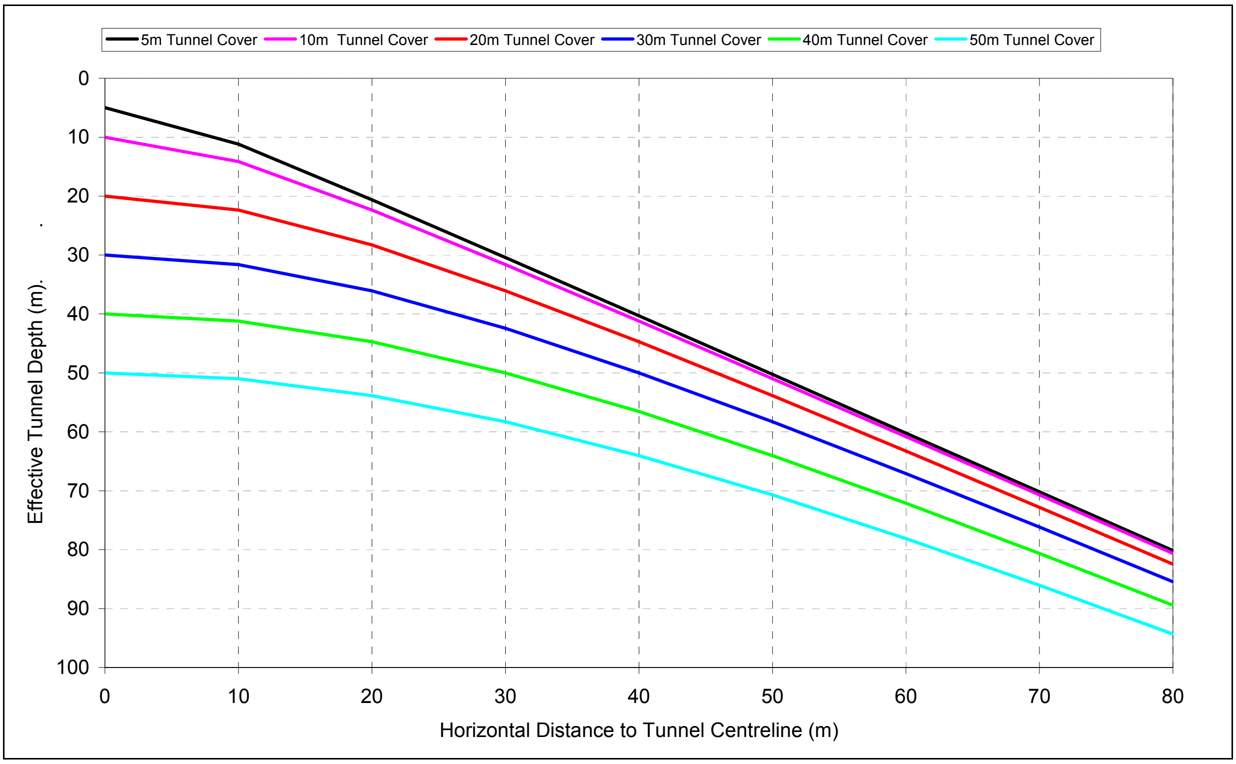
10.2 Tunnel Slant Distance to Sensitive Properties

The crown of the tunnel is nominally 8 m above a control line at the lateral centre-line of the tunnel at the finished road pavement. The actual height of the excavated crown relative to the control line will vary depending on the number of traffic lanes, method of construction (roadheader versus TBM) and localised tunnel enlargements for accommodation of services. The tunnel crown below existing ground level was supplied to Heggies by the JV for this assessment.

The “slant distance” from the crown of the tunnel to nearby building footings is a primary variable controlling the reduction of ground vibration transmitted into buildings from tunnelling.

The relationship between the vertical distance from tunnel crown to ground level, the side-line distance to a building and the slant distance is presented in **Figure 11**.

Figure 11 Determination of Slant Distance from Tunnel to a Building



Cross-street locations have been referenced in the vibration emission prediction tables (rather than specific chainage distances) to enhance interpretation of the data.

The relative level of building footings near the tunnel alignment has been assumed to be the same as the natural ground level immediately above the tunnel. Slant distances have been calculated on this basis.

No detailed investigations have been undertaken to confirm actual footing depths.

10.3 Vibration Impacts

10.3.1 Overview

Specific vibration levels have been predicted using the indicative ground vibration levels (based on the measurement results for tunnelling methods in **Table 27**) and the slant distances to the receivers.

The potential impacts of vibration on buildings have been assessed by comparing the predicted vibration levels using the guide values for minimising the risk of cosmetic (superficial) building damage summarised in **Table 5** - and/or also statutory requirements - as appropriate. The potential impacts of vibration on people have been assessed using the guideline values for subjective human disturbance response given in **Table 7**.

Summaries of the key parameters describing the impacts on buildings and residents along the route are presented in **Table 54** and **Table 56**. A summary of the indicative extent of possible human perception resulting from the tunnelling operations (ie road header or TBM) and from blast vibration is shown in **Table 57**.

In order to address community concerns regarding potential vibration impacts in a pro-active manner, a range of response management measures will be implemented prior to and/or during tunnelling operations. The specific management response measures are dependent on the predicted levels of possible impacts on buildings and their occupants - and are described in **Table 53**.

Table 53 Potential Vibration Impact Response Management Measures

Predicted Effect of Tunnelling Vibration Emissions	Pre Notification to Building Occupants	Building Condition Survey	Building Sensitivity Study (Refer Note 1)	Vibration Monitoring
Not felt	-	-	-	-
Threshold of perception	-	-	-	
Barely noticeable	✓		✓	
Sleep disturbance Note 2	✓		✓	✓
Noticeable	✓		✓	✓
Easily noticeable	✓	✓	✓	✓
Strongly noticeable	✓	✓	✓	✓
Very strongly noticeable	✓	✓	✓	✓

Note 1: This only applies for specific sensitive buildings identified in **Section 3** of this report.
Note 2: This category is not within **Table 77**, and is defined to be 0.5 mm/s. Refer **Section 10.3.5**

For blasting, the Maximum Instantaneous Charge (MIC) of explosive used in the design of the blast and the distance to a receiver dictate the likely received levels of vibration. Explosive MICs will be selected to ensure that predicted vibration levels do not exceed permissible limits. The representative blast MIC was determined based on previous trial blasts in Brisbane - and is a first approximation.

Wherever blasting is undertaken, building condition surveys, building sensitivity studies and vibration monitoring is recommended. The results of these surveys will feed back into the blast design process over time (according to **Table 5**) to provide greater confidence with the blast design and implementation processes (which will commence with trial blasting designed to achieve conservatively low predicted vibration emission levels).

Table 54 Tunnelling Vibration Summary – Properties on Northern Side of Mainline Tunnel

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Vibration Level	Guide Value (G) or Statutory Limit (L) for cosmetic damage	Possible Impact NF - Not felt TP - Threshold of perception BN - Barely noticeable SD – Sleep Disturbance N - Noticeable EN - Easily noticeable SN - Strongly noticeable VSN - Very strongly noticeable	Mitigation P = pre notification BCS = building condition survey BSS = building sensitive study M = monitoring
Toowong Cemetery[1]	cemetery	43.22 m – 13.87 m	TBM	0.705 to 5.594 mm/s	2 mm/s (G)	SN	P,BCS,BSS,M
Frederick St to Birdwood Tce	Residential	58.17 m - 24.42 m	TBM	0.410 to 1.996 mm/s	5 mm/s (G)	N (approaching EN)	P,BCS,M
Birdwood Tce to Annie St	Residential	57.31 m – 39.01 m	Roadheader Blasting	0.006 to 0.013 mm/s 2.471 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	P, BCS, M
Annie St to Carrington St	Residential	68.79 m – 51.14 m	TBM	0.302 to 0.519 mm/s	5 mm/s (G)	SD	P,M
Carrington St to Beck St	Residential	58.90 m – 30.43 m	TBM	0.401 to 1.337 mm/s	5 mm/s (G)	N	P,M
Beck St to Ewart St	Residential	29.90 m – 22.22 m	TBM	1.380 to 2.370 mm/s	5 mm/s (G)	EN	P,BCS,M
Ewart St to Bowler St	Residential	44.28 m - 25.55 m	TBM	0.675 to 1.838 mm/s	5 mm/s (G)	N (approaching EN)	P,BCS,M
Bowler St to Plunkett St	Residential	30.06 m – 8.53 m	Roadheader Blasting	0.020 to 0.183 mm/s 0.118 kg	5 mm/s (G) 10 mm/s (L)	TP SN, CC	P, BCS, M
Plunkett St to Cambridge St[2]	Residential	42.71 m – 10.30 m	TBM	0.721 to 9.621 mm/s	5 mm/s (G)	SN	P,BCS,M
Cambridge St to Lower Clifton Tce	Residential	46.90 m – 28.75 m	TBM	0.608 to 1.482 mm/s	5 mm/s (G)	N	P,M
Lower Clifton Tce to Inner City Bypass[2]	Residential	26.47 m – 11.86 m	TBM	1.723 to 7.406mm/s	5 mm/s (G)	SN	P,BCS,M

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Vibration Level	Guide Value (G) or Statutory Limit (L) for cosmetic damage	Possible Impact NF - Not felt TP - Threshold of perception BN - Barely noticeable SD – Sleep Disturbance N - Noticeable EN - Easily noticeable SN - Strongly noticeable VSN - Very strongly noticeable	Mitigation P = pre notification BCS = building condition survey BSS = building sensitive study M = monitoring
Toowong Cemetery[1]	cemetery	43.22 m – 13.87 m	TBM	0.705 to 5.594 mm/s	2 mm/s (G)	SN	P,BCS,BSS,M
Frederick St to Birdwood Tce	Residential	58.17 m - 24.42 m	TBM	0.410 to 1.996 mm/s	5 mm/s (G)	N (approaching EN)	P,BCS,M
Birdwood Tce to Annie St	Residential	57.31 m – 39.01 m	Roadheader Blasting	0.006 to 0.013 mm/s 2.471 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	P, BCS, M
Annie St to Carrington St	Residential	68.79 m – 51.14 m	TBM	0.302 to 0.519 mm/s	5 mm/s (G)	SD	P,M
Carrington St to Beck St	Residential	58.90 m – 30.43 m	TBM	0.401 to 1.337 mm/s	5 mm/s (G)	N	P,M
Beck St to Ewart St	Residential	29.90 m – 22.22 m	TBM	1.380 to 2.370 mm/s	5 mm/s (G)	EN	P,BCS,M
Ewart St to Bowler St	Residential	44.28 m - 25.55 m	TBM	0.675 to 1.838 mm/s	5 mm/s (G)	N (approaching EN)	P,BCS,M
Bowler St to Plunkett St	Residential	30.06 m – 8.53 m	Roadheader Blasting	0.020 to 0.183 mm/s 0.118 kg	5 mm/s (G) 10 mm/s (L)	TP SN, CC	P, BCS, M
Plunkett St to Cambridge St[2]	Residential	42.71 m – 10.30 m	TBM	0.721 to 9.621 mm/s	5 mm/s (G)	SN	P,BCS,M
Cambridge St to Lower Clifton Tce	Residential	46.90 m – 28.75 m	TBM	0.608 to 1.482 mm/s	5 mm/s (G)	N	P,M
Lower Clifton Tce to Inner City Bypass[2]	Residential	26.47 m – 11.86 m	TBM	1.723 to 7.406mm/s	5 mm/s (G)	SN	P,BCS,M

Note 1 – Vibration level predicted to exceed 2 mm/s guide value.

Note 2 – Vibration level predicted to exceed 5 mm/s guide value.

Table 55 Tunnelling Vibration Summary – Properties on Southern Side of Mainline Tunnel

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Vibration Level	Guide Value (G) or Statutory Limit (L) for cosmetic damage	Possible Impact NF - Not felt TP - Threshold of perception BN - Barely noticeable SD – Sleep Disturbance N - Noticeable EN - Easily noticeable SN - Strongly noticeable VSN - Very strongly noticeable	Mitigation P = pre notification BCS = building condition survey BSS = building sensitive study M = monitoring
Toowong Cemetery[1]	cemetery	40.73 m - 10.45 m	TBM	0.786 to 9.371 mm/s	2 mm/s (G)	SN (approaching VSN)	P,BCS,BSS,M
Frederick St to Birdwood Tce	Residential	56.89 m - 23.73 m	TBM	0.427 to 2.103 mm/s	5 mm/s (G)	EN	P,BCS,M
Birdwood Tce to Payne St	Residential	57.59 m - 36.06 m	Roadheader Blasting	0.006 to 0.014 mm/s 2.112 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	P, BCS, M
Payne St to Carrington St	Residential	66.69 m - 36.92 m	TBM	0.320 to 0.940 mm/s	5 mm/s (G)	N	P,M
Carrington St to Beck St	Residential	65.98 m - 30.47 m	TBM	0.326 to 1.333 mm/s	5 mm/s (G)	N	P,M
Beck St to Ewart St	Residential	30.15 m - 25.45 m	TBM	1.359 to 1.851 mm/s	5 mm/s (G)	N (approaching EN)	P,BCS,M
Ewart St to Latrobe TCE	Residential	43.01 m - 28.24 m	TBM	0.711 to 1.531 mm/s	5 mm/s (G)	N	P,M
Latrobe TCE to Plunkett St	Residential	42.88 m – 9.84	Roadheader Blasting	0.011 to 0.142 mm/s 0.157 kg	5 mm/s (G) 10 mm/s (L)	TP SN, CC	P, BCS, M
Plunkett St to Cambridge St[2]	Residential	43.28 m - 17.15 m	TBM	0.703 to 3.800 mm/s	5 mm/s (G)	EN	P,BCS,M
Cambridge St to Lower Clifton Tce	Residential	46.10 m - 25.11 m	TBM	0.627 to 1.897 mm/s	5 mm/s (G)	N (approaching EN)	P,BCS,M
Lower Clifton Tce to Inner City Bypass[2]	Residential	23.43 m - 12.00 m	TBM	2.152 to 7.283 mm/s	5 mm/s (G)	SN	P, BCS, M

Note 1 – Vibration level predicted to exceed 2 mm/s guide value.

Note 2 – Vibration level predicted to exceed 5 mm/s guide value.

Table 56 Roadheader Tunnelling Vibration Summary – Northern Link On/Off Tunnel Ramps

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Vibration Level,	Guide Value (G) or Statutory Limit (L) for cosmetic damage	Possible Impact NF - Not felt TP - Threshold of perception BN - Barely noticeable SD – Sleep Disturbance N - Noticeable EN - Easily noticeable SN - Strongly noticeable VSN - Very strongly noticeable CC = cosmetic cracking	Mitigation P = pre notification BCS = building condition survey BSS = building sensitive study M = monitoring
Toowong Connection							
On-Ramp from Morley St to Thorpe St	Residential	17.20 m - 4.17 m	Roadheader Blasting	0.053 to 0.643mm/s 0.028 kg	5 mm/s (G) 10 mm/s (L)	SD SN, CC	P,M P, BCS, M
On-Ramp from Thorpe St to Birdwood Tce	Residential	62.04 m - 8.03 m	Roadheader Blasting	0.006 to 0.203mm/s 0.105 kg	5 mm/s (G) 10 mm/s (L)	TP SN, CC	- P, BCS, M
Off-Ramp from Morley St to Thorpe St	Residential	19.04 m - 6.93 m	Roadheader Blasting	0.045 to 0.263mm/s 0.078 kg	5 mm/s (G) 10 mm/s (L)	TP SN, CC	- P, BCS, M
Off-Ramp from Thorpe St to Birdwood Tce	Residential	58.10 m - 11.23 m	Roadheader Blasting	0.006 to 0.113mm/s 0.205 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	- P, BCS, M
Kelvin Grove Connection							
On-Ramp from Bowler St to Charteris St	Residential	13.27 m - 39.03 m	Roadheader Blasting	0.084 to 0.013mm/s 0.286 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	- P, BCS, M
On-Ramp from Charteris St to Kelvin Grove Rd	Residential	12.41 m - 26.15 m	Roadheader Blasting	0.094 to 0.025mm/s 0.250 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	- P, BCS, M
Off-Ramp from Charlotte St to Cambridge St	Residential	53.62 m - 11.28 m	Roadheader Blasting	0.007 to 0.112mm/s 0.207 kg	5 mm/s (G) 10 mm/s (L)	NF SN, CC	- P, BCS, M
Off-Ramp from Cambridge St to Kelvin Grove Rd	Residential	34.95 m - 5.36 m	Roadheader Blasting	0.015 to 0.413mm/s 0.047 kg	5 mm/s (G) 10 mm/s (L)	BN SN, CC	P P, BCS, M

Table 57 Indicative Radius of Perceptible TBM and Blasting Vibration

Tunnelling Method	Tunnel Cover	Indicative Radius of Vibration Note 1 (0.2 mm/s threshold)	Indicative Radius of Possible Sleep Disturbance (0.5 mm/s threshold)
TBM	10 m	80 m	50 m
	20 m	78 m	46 m
	30 m	75 m	40 m
	40 m	70 m	30 m
	50 m	60 m	10 m
Blasting	**Maximum Instantaneous Charge**	**Indicative Radius of Perceptible Vibration (0.2 mm/s threshold)**	**Sleep Disturbance Not Applicable to Daytime Blasting**
	5 kg	350 m	n/a
	1 kg	150 m	n/a
	0.2 kg	70 m	n/a

Note 1 – Correlates to low probability of reaction

10.3.2 General Discussion

It can be seen from a comparison of the criteria and guideline levels in **Table 5** and **Table 9** that the threshold vibration levels below which cosmetic building damage from transient vibrations (eg blasting) do not occur, are comparable to vibration levels readily accepted as being normal by people in buildings during the daytime. Thus, in general terms, the objective of protecting buildings from excessive blast vibrations generally results in vibration levels that people will accept, provided there is an effective community consultation process in place to ensure that people are well informed of the works and the nature of their vibration emissions.

During the night-time period, it could be expected that blasting would result in significant adverse comment. Blasting will therefore normally be avoided during the night-time period.

10.3.3 Roadheading

There are shallow tunnel areas at both the Toowong (on and off ramps) and Kelvin Grove (off ramp only) areas where vibration from roadheaders may be perceptible. No major on-going vibration mitigation measures or impact response management procedures are anticipated to be necessary for this type of tunnelling. It is recommended however that vibration measurements/monitoring be conducted during the start of the tunnelling works to confirm the predictions (based on the actual plant items being used) and to allay any concerns that the community may express.

10.3.4 Blasting

Depending on the number of blastholes and the millisecond delays used between successive detonations, tunnel face blasting typically results in a series of short vibration "events" lasting several seconds. Apart from limiting the size of the charge, the normal mitigation method in relation to human comfort impacts is to give clear and concise pre-notification to all persons in the area. People will "hear" the blast, although vibration (and noise) levels are usually relatively low. It is imperative that the community be properly advised so that ill-informed perceptions do not cause unnecessary concern.

It is often the case with projects where blasting is carried out that a regular schedule is established whereby people come to anticipate blast vibrations at a set time with minimal "startle effects" or other concerns.

If drill and blast methods are required, the following guidelines will be considered by the project team:

- Appropriate attention to blast design, with a low MIC.
- Effective pre-warnings and coordination of the timing of the blast activities to minimise impacts on specific healthcare operations via the community consultation team.
- Monitoring of the blast emissions and correlation of the readings with consultation with the staff members.

In general, minimisation of impacts on buildings and their occupants is achieved by appropriate blast design. This usually involves commencing with a small, controlled blast design with low emission levels and then progressively increasing charge weights to establish prudent blast design parameters. It is a requirement of Brisbane City Council to conduct pre- and post-blasting Building Condition Surveys where it is considered there may be potential for cosmetic (superficial) building damage.

10.3.5 Tunnel Boring Machine

It is proposed to operate the TBMs on a near continuous basis. Sleep disturbance may result if the vibration levels from continuous vibration levels are higher than 0.5 mm/s which is predicted to be the case for many residences above the mainline tunnels.

It should be noted that the subjective responses of individual people to vibration in their dwellings is variable. Tolerances and susceptibility to vibration vary markedly. The 0.5 mm/s night-time guideline vibration level for this project is considered conservatively low and some people may be comfortable with higher levels.

As indicated by the levels in **Table 54** and **Table 55,** vibration from the TBMs may potentially exceed the building damage goals at the Toowong Cemetery, Charlotte Street and Normanby Terrace areas. Building condition surveys should be conducted prior to the tunnelling works and monitoring during the works will be required.

10.4 Regenerated Noise Impacts

Possible regenerated noise impacts and mitigation options along the tunnel alignments are summarised in **Table 59**, **Table 60** and **Table 61**. A summary of the indicative extent of possible human perception of Roadheader and TBM regenerated noise, and possible sleep disturbance from regenerated noise, is shown in **Table 62**.

Regenerated noise impacts have been assessed by comparing the indicative regenerated noise levels associated with the proposed tunnelling methods with the slant distance, type of building and tunnelling method data (refer to **Table 59** to **Table 61**).

Possible impacts of regenerated noise have been assessed using the guideline values for acceptable noise levels inside building in AS/NZS 2107, summarised in **Table 38** - although this standard refers to noise from a prevailing ambient noise such as road traffic - and not to a source of limited duration such as tunnel construction. Regenerated noise from tunnelling can usually only be perceived in rooms that are well insulated from outside air-borne traffic noise. It is therefore reasonable to use the AS/NZS 2107 guideline values for living areas and bedrooms in dwellings near 'minor roads' for the assessment.

In order to assist in quantifying the impacts on residents, the flowing descriptors were used:

- Very Low – <35 dBA
- Low – 35 dBA to 40 dBA
- Moderate – 40 dBA to 45 dBA
- High – >45 dBA (which corresponds to the potential on-set of sleep disturbance in a residential area (refer to **Table 25**).

In order to address community concerns regarding potential regenerated-noise impacts in a pro-active manner, a range of response management measures will be implemented prior to and/or during tunnelling operations. The specific management response measures are dependent on the predicted levels of possible impacts on building occupants and are described in **Table 56**.

- **Table 58 Potential Regenerated Noise Impact Response Management Measures**

Level of Regenerated Noise	Pre Notification	Monitoring
Very Low	-	-
Low	✓	✓ (depending upon community sensitivity)
Moderate	✓	✓
High	✓	✓

Tunnel blasting can generate regenerated noise, although the primary community concern is vibration. Impacts from blasting operations are therefore usually managed by regulated the vibration emission levels.

The potential regenerated noise levels of rock drills have not been specifically calculated at all receptor locations. As a guide, the levels of regenerated rock drill noise are usually lower than regenerated noise levels from roadheader operations.

Table 59 Tunnelling Regenerated Noise Summary – Properties on Northern Side of Mainline Tunnel

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Regenerated Noise Level (dBA)[1]	NIAPSP Sleep Disturbance Value (dBA)	Possible Impact Very Low: <35 dBA Low: 35 – 40 dBA Moderate: 40 to 45 dBA High: > 45 dBA (equates to sleep disturbance for residential properties)	Mitigation P = pre notification M = monitoring
Frederick St to Birdwood Tce	Residential	58.17 m - 24.42 m	TBM	40 dBA to 51 dBA	45 night	Moderate to High	P,M
Birdwood Tce to Annie St	Residential	57.31 m - 39.01 m	Roadheader	27 dBA to 32 dBA	45 night	Very Low	
Annie St to Carrington St	Residential	68.79 m – 51.14 m	TBM	38 dBA to 42 dBA	45 night	Low to Moderate	P,M
Carrington St to Beck St	Residential	58.90 m - 30.43 m	TBM	40 dBA to 48 dBA	45 night	Moderate to High	P,M
Beck St to Ewart St	Residential	29.90 m - 22.22 m	TBM	49 dBA to 52 dBA	45 night	High	P,M
Ewart St to Bowler St	Residential	44.28 m - 25.55 m	TBM	43 dBA to 51 dBA	45 night	Moderate to High	P,M
Bowler St to Plunkett St	Residential	30.06 m – 8.53 m	Roadheader	36 dBA to 52 dBA	45 night	Low to High	P,M
Plunkett St to Cambridge St	Residential	42.71 m - 10.30 m	TBM	44 dBA to 62 dBA	45 night	Moderate to High	P,M
Cambridge St to Lower Clifton Tce	Residential	46.90 m - 28.75 m	TBM	43 dBA to 49 dBA	45 night	Moderate to High	P,M
Lower Clifton Tce to Inner City Bypass	Residential	26.47 m - 11.86 m	TBM	50 dBA to 60 dBA	45 night	High	P,M

Note 1 - LAeq values predicted to be 5 dBA lower than LAmax (based on preliminary NSBT measurements).

Table 60 Tunnelling Regenerated Noise Summary – Properties on Southern Side of Mainline Tunnel

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Regenerated Noise Level (dBA)[1]	NIAPSP Sleep Disturbance Value (dBA)	Possible Impact Very Low: <35 dBA Low: 35 – 40 dBA Moderate: 40 to 45 dBA High: > 45 dBA (equates to sleep disturbance for residential properties)	Mitigation P = pre notification M = monitoring
Frederick St to Birdwood Tce	Residential	56.89 m - 23.73 m	TBM	40 dBA to 52 dBA	45 night	Moderate to High	P,M
Birdwood Tce to Payne St	Residential	57.59 m - 36.06 m	Roadheader	27 dBA to 33 dBA	45 night	Very Low	
Payne St to Carrington St	Residential	66.69 m – 36.92 m	TBM	38 dBA to 46 dBA	45 night	Low to High	P,M
Carrington St to Beck St	Residential	65.98 m - 30.47 m	TBM	38 dBA to 48 dBA	45 night	Low to High	P,M
Beck St to Ewart St	Residential	30.15 m - 25.45 m	TBM	48 dBA to 50 dBA	45 night	High	P,M
Ewart St to Latrobe TCE	Residential	43.01 m - 28.24 m	TBM	44 dBA to 49 dBA	45 night	Moderate to High	P,M
Latrobe TCE to Plunkett St	Residential	42.88 m – 9.84 m	Roadheader	30 dBA to 50 dBA	45 night	Very Low to High	P,M
Plunkett St to Cambridge St	Residential	43.28 m - 17.15 m	TBM	44 dBA to 56 dBA	45 night	Moderate to High	P,M
Cambridge St to Lower Clifton Tce	Residential	46.10 m - 25.11 m	TBM	43 dBA to 51 dBA	45 night	Moderate to High	P,M
Lower Clifton Tce to Inner City Bypass	Residential	23.43 m - 12.00 m	TBM	52 dBA to 60 dBA	45 night	High	P,M

Note 1 - LAeq values predicted to be 5 dBA lower than LAmax (based on preliminary NSBT measurements).

Table 61 Roadheader Tunnelling Regenerated Noise Summary – Northern Link On/Off Tunnel Ramps

Tunnel Section	Type of Building	Depth of Tunnel Crown	Excavation Method	Indicative max. Regenerated Noise Level (dBA)[1]	NIAPSP Sleep Disturbance Value (dBA)	Possible Impact Very Low: <35 dBA Low: 35 – 40 dBA Moderate: 40 to 45 dBA High: > 45 dBA (equates to sleep disturbance for residential properties)	Mitigation P = pre-notification M = monitoring
Toowong Connection							
Southern On-Ramp from Morley St to Thorpe St	Residential	17.20 m - 4.17 m	Roadheader	43 dBA to 61 dBA	45 night	Moderate to High	P,M
Southern On-Ramp from Thorpe St to Birdwood Tce	Residential	62.04 m - 8.03 m	Roadheader	26 dBA to 53 dBA	45 night	Low to High	P,M
Southbound Off-Ramp from Morley St to Thorpe St	Residential	19.04 m - 6.93 m	Roadheader	42 dBA to 55 dBA	45 night	Moderate to High	P,M
Southbound Off-Ramp rom Thorpe St to Birdwood Tce	Residential	58.10 m - 11.23 m	Roadheader	27 dBA to 48 dBA	45 night	Low to High	P,M
Kelvin Grove Connection							
Northern On- Ramp from Bowler St to Charteris St	Residential	13.27 m - 39.03 m	Roadheader	32 dBA to 46 dBA	45 night	Very Low to High	P,M
Northern On- Ramp from Charteris St to Kelvin Grove Rd	Residential	12.41 m - 26.15 m	Roadheader	37 dBA to 47 dAB	45 night	Low to High	P,M
Northern Off- Ramp from Charlotte St to Cambridge St	Residential	53.62 m - 11.28 m	Roadheader	28 dBA to 48 dBA	45 night	Very Low to High	P,M
Northern Off- Ramp from Cambridge St to Kelvin Grove Rd	Residential	34.95 m - 5.36 m	Roadheader	34 dBA to 58 dBA	45 night	Very Low to High	P,M

Note 1 - LAeq values predicted to be 5 dBA lower than LAmax (based on preliminary NSBT measurements).

Table 62 Radius of Perceptible Regenerated Noise versus Tunnel Cover

Tunnelling Method	Tunnel Cover	Indicative Radius to achieve a level of 40 dBA Regenerated Noise[1]	Indicative Radius of Possible Sleep Disturbance (45 dBA threshold)
Roadheader	10 m	20 m	11 m
	20 m	9 m	Below threshold
	30 m	Below threshold	Below threshold
	40 m	Below threshold	Below threshold
	50 m	Below threshold	Below threshold
TBM	10 m	58 m	39 m
	20 m	56 m	35 m
	30 m	51 m	26 m
	40 m	43 m	At threshold
	50 m	31 m	Below threshold

Note 1 – Which equates to the maximum AS2107 LAeq noise level recommended for temporary noise sources given the 5 dBA relationship predicted between LAmax and LAeq noise levels for both TBM and roadheader driven tunnelling.

10.4.1 Roadheading

Predicted worst-case regenerated noise levels from roadheading exceed the AS2107 guide values at many of the locations assessed in **Table 61**. Sleep disturbance impacts are also likely to result from Northern Link on/off ramp tunnelling due to the shallow tunnel depths. All practicable mitigation measures will be required to minimise the impact from these works. Mitigation measures are detailed in **Section 10.4.5**.

10.4.2 Tunnel Boring Machine

Tolerances to noise vary markedly. Some people may be comfortable with much higher noise levels at night than the nominated 45 dBA sleep disturbance value, depending on many factors, including how the sleeping areas are currently affected by traffic noise.

By comparing the possible zone of influence of TBM regenerated noise in **Table 62** with the possible zone of influence of TBM vibration in **Table 57**, it can be seen that the predicted extent of potential impacts of TBM regenerated noise and vibration are similar.

Worst-case predictions indicate that it is likely that regenerated noise from the TBM will be noticeable in many buildings above the tunnel alignment. All practicable mitigation measures detailed in **Section 10.4.5** are required to minimise the impact from these works.

10.4.3 Sensitivity of Tunnel Boring Machine Predictions to Piled Footings

Further investigations will be required during design development and detailed construction design to determine more confidently where piles have been constructed so that more detailed predictions can be undertaken.

10.4.4 Low Frequency Noise Impacts

The frequency range of infrasound is normally taken to be below 20 Hz and audible noise from 20 Hz to 20,000 Hz. Contrary to this interpretation, noise at frequencies below 20 Hz can be audible, however tonality is lost below 16 – 18 Hz thus losing a key element of perception. Low frequency noise spans the infrasonic and audible ranges and may be considered as the range from about 10 Hz to 200 Hz.

Infrasound and low frequency noise may result from pumps, compressors, diesel engines, aircraft, shipping, combustion, air turbulence, wind and fans. Regenerated or structure borne noise originating as vibration from tunnelling activities (eg TBMs and roadheaders) may also be a source of low frequency noise. For Northern Link, driven tunnelling is considered to be the only potentially significant source of low frequency noise. Other potential sources, such as compressors and diesel engines may be mitigated by means of enclosures, increasing separation distances, limiting use etc.

Guidance on the assessment of low frequency noise impacts can be sought from the (Queensland EPA) Ecoaccess Guideline *Assessment of Low Frequency Noise*. The intent of these criteria is to accurately assess annoyance and discomfort to persons at noise sensitive places. The guideline assesses both infrasound – below 20 Hz (Part A) and low frequency noise – above 20 Hz (Part B).

The following is an assessment of low frequency noise impacts associated with the Northern Link Project.

10.4.4.1 Part A – Infrasound (<20 Hz)

The G-weighting function is used to determine annoyance due to infrasound. G-weighted noise levels below 85-90 dB(G) are not normally significant in terms of human perception and are not annoying. The average hearing threshold for single tones is usually about 95 to 100 dB(G).

Recommended infrasound limit values are:

- 85 dB(G) inside dwellings during the day, evening and night and inside classrooms and offices.
- 90 dB(G) for occupied rooms in commercial enterprises.

From regenerated noise measurements of two 12 m diameter TBMs and roadheaders conducted within commercial type buildings (RNA pavilion and child care centre respectively) above the North South Bypass Tunnel (NSBT), the resultant one-third octave band spectrum for both TBM and roadheader was analysed to determine the G-weighted sound pressure levels. The analysis results are shown in **Table 63**.

Table 63 TBM and Roadheader G-weighted Sound Pressure Levels

Tunnelling Plant	12.5Hz	16Hz	20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	Overall Level
Tunnel Boring Machine											
Measured TBM - NSBT	58 dB	61 dB	60 dB	67 dB	67 dB	57 dB	53 dB	51 dB	51 dB	52 dB	
Factored to achieve EIS mid-point Level[1]	75 dB	78 dB	77 dB	84 dB	84 dB	74 dB	70 dB	68 dB	68 dB	69 dB	
G-Weighting	4.0	7.7	9.0	3.7	-4.0	-12.0	-20.0	-28.0	-36.0	-44.0	
G-weighted TBM @ 10 m	79	86	86	88	80	62	50	40	32	25	**92 dBG**
Roadheader											
Measured Roadheader - NSBT	55 dB	56 dB	57 dB	55 dB	55 dB	54 dB	53 dB	51 dB	51 dB	50 dB	
Factored to achieve EIS mid-point Level[2]	69 dB	70 dB	71 dB	69 dB	69 dB	68 dB	67 dB	65 dB	65 dB	64 dB	
G-Weighting	4.0	7.7	9.0	3.7	-4.0	-12.0	-20.0	-28.0	-36.0	-44.0	
G-weighted Roadheader @ ~5m	73	78	80	73	65	56	47	37	29	20	**83 dBG**

Note 1 – Mid-point regenerated noise level for a hard rock TBM at 10 m taken to be LAmax 63 dBA (refer to **Table 28**).

Note 2 – Mid-point regenerated noise level for a roadheader at 5 m taken to be LAmax 59 dBA (refer to **Table 28**).

The results in **Table 63** indicate that for a TBM operating at approximately 10 m from a receiver building, the Ecoaccess guideline values for infrasound will be exceeded for dwellings.

Repeating the analysis process in **Table 63** to achieve the recommended limit value for infrasound, and hence avoid annoyance, indicates that the required minimum (conservative) operating distance is 30 m for a hard rock TBM.

From the roadheader measurements conducted during NSBT tunnelling, the results from the G-weighted sound pressure level analysis shown in **Table 63** indicates that recommended infrasound limits will be complied with during tunnelling works that occur approximately 5 m from sensitive receiver buildings including dwellings, classrooms and offices.

It should be noted that very limited one-third octave spectral data exists for tunnelling operations in local strata and that the above analysis is based on initial results from NSBT measurements. Therefore it is recommended that further analysis be undertaken as additional one-third octave spectral data becomes available prior to finalising a mitigation strategy where infrasound is found to be an issue.

10.4.4.2 Part B – Low Frequency Noise (≥20 Hz)

Low frequency noise sources typically exhibit a spectrum that shows a general increase in sound pressure level with decrease in frequency. Annoyance due to low frequency noise can be high even though the actual measured level is relatively low and typically occurs in quiet environments such as residential and office spaces. This occurs as a result of the absence of high frequency components (which can have a masking effect) caused by transmission loss through the building envelope.

The main elements of the Ecoaccess guideline assessment include:

- *The low frequency noise criterion adopted for initial screening inside home environments in terms of Linear, A-weighted and one-third octave band sound pressure levels in the range 20 to 200 Hz;*
- *The comparison of one-third octave band low frequency sound with the values for L_{HS} of the ISO median hearing threshold level for the best 10% of the aged population (55-60 years old) to initially establish auditory perception.*

Assessment Procedure

The Ecoaccess low frequency noise assessment procedure involves the following:

- Step 1 Initial Screening – *Where a noise immission occurs exhibiting an unbalanced frequency spectra, the overall sound pressure level inside residences should not exceed 50 dB(Linear) to avoid complaints of low frequency noise annoyance. If the dB(Linear) measurements exceeds the dB(A) measurement by more than 15 dB, a one-third octave band measurement in the frequency range 20 to 200 Hz should be carried out.*

- Step 2 Audibility Assessment – *The following checks should be made to establish whether the noise contains dominant low-frequency components:*
  - *Determine if L_{LINeq} – LAeq(15minutes) > 15 dB*
  - *Compare measured one-third octave band levels with the L_{HS} values of the median hearing threshold level for the best 10% of the older population (55-60 Years old) to determine the degree of low frequency noise audibility.*
  - *Check for the existence of an amplitude-modulating component*

- Step 3 Annoyance due to Tonal Noise – *Check if the sound pressure level in a particular one-third octave band is 5 dB or more above the levels in the two neighbouring bands.*

- Step 4 Annoyance due to Non-tonal Noise – *To establish annoyance for non-tonal noise in the frequency range 10 Hz to 160 Hz, A-weighting network corrections are applied to the one-third octave spectra measured indoors and the overall A-weighted value, called $L_{pA,LF}$ is assessed against a recommended limits:*
  - *Dwelling – evening & night* $L_{pA,LF}$ *20 dB*
  - *Dwelling – day* $L_{pA,LF}$ *25 dB*
  - *Classroom, office* $L_{pA,LF}$ *30 dB*
  - *Commercial enterprises* $L_{pA,LF}$ *35 dB*

Step 1 – Initial Screening

NSBT TBM and roadheader measurement results, over slant distances of 30 m and 15 m respectively (shown in **Table 64),** indicate that the 50 dB(Linear) level will be exceeded when tunnelling at close distance. The results in **Table 64** also indicate that the linear sound pressure level is more than 15 dB higher than the A-weighted sound pressure level.

Compliance with the 50 dB(Linear) level will likely be achieved at distances of (conservatively) 200 m and 50 m or greater for the TBM and Roadheader respectively.

- **Table 64 Comparison of Linear and A-weighted TBM and Roadheader Sound Pressure Levels**

Tunnelling Plant	12.5Hz	16Hz	20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz
TBM Linear SPL	58 dB	61 dB	60 dB	67 dB	67 dB	57 dB	53 dB	51 dB	51 dB
TBM A-weighted SPL	-5 dBA	5 dBA	10 dBA	22 dBA	27 dBA	23 dBA	23 dBA	25 dBA	29 dBA
Roadheader Linear SPL	55 dB	56 dB	57 dB	55 dB	55 dB	54 dB	53 dB	51 dB	51 dB
Roadheader A-weighted SPL	-8 dBA	-1 dBA	7 dBA	10 dBA	16 dBA	19 dBA	23 dBA	25 dBA	29 dBA
	100Hz	**125Hz**	**160Hz**	**200Hz**	**315Hz**	**400Hz**	**Overall**		
TBM Linear SPL	52 dB	49 dB	48 dB	45 dB	37 dB	30 dB	71 dBA		
TBM A-weighted SPL	33 dBA	33 dBA	35 dBA	34 dBA	28 dBA	23 dBA	41 dBA		
Roadheader Linear SPL	50 dB	48 dB	48 dB	43 dB	38 dB	30 dB	64 dB		
Roadheader A-weighted SPL	31 dBA	32 dBA	35 dBA	32 dBA	29 dBA	23 dBA	40 dBA		

Note – TBM data at slant distance of 30m; Roadheader data at slant distance of 15m

Step 2 – Audibility Assessment

It is recognised that regenerated noise from driven tunnelling plant will be audible at times during construction and therefore steps 3 and 4 of the Ecoaccess guideline are undertaken below.

Step 3 – Tonal Noise Assessment

The one-third octave band spectra from measurements of the NSBT TBMs and roadheaders do not exhibit tonality.

Step 4 – Annoyance due to Non-tonal Noise

The assessment results (A-weighted corrections) for annoyance due to non-tonal noise are presented in **Table 65**.

Table 65 A-weighted Corrected Noise Levels for TBM and Roadheader Annoyance

Tunnelling Plant	12.5Hz	16Hz	20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz
TBM @ ~10 m	12 dBA	22 dBA	27 dBA	39 dBA	44 dBA	40 dBA	40 dBA	42 dBA	46 dBA
Roadheader @ ~5m	6 dBA	13 dBA	21 dBA	24 dBA	30 dBA	33 dBA	37 dBA	39 dBA	43 dBA
	100Hz	**125Hz**	**160Hz**	**$L_{pA,LF}$**					
TBM @ ~10 m	50 dBA	50 dBA	52 dBA	**57 dBA**					
Roadheader @ ~5m	45 dBA	46 dBA	49 dBA	**52 dBA**					

The A-weighted corrected one-third octave noise levels presented in **Table 65** for TBM and roadheader, similar to the type that will be used for the Northern Link Project, indicate that the recommended limits applicable to non-tonal low frequency noise will be exceeded for all receiver types when operating in close proximity.

At distances of approximately 190 m and 70 m (for TBM and roadheader respectively) or greater, compliance with the annoyance threshold ($L_{pA,LF}$ 20 dB) would likely be achieved for dwellings during the evening and night-time period.

As discussed in **Section 10.4.4.1**, the spectral data used for the present assessment is based on a relatively small measurement sample. It is recommended that a detailed low frequency noise assessment be carried out for the Northern Link Project as additional data becomes available, for example, data obtained from measurements carried out within a typical residential dwelling.

The Ecoaccess guideline includes a chapter on potential noise reduction measures which focus primarily on design such as incorporating silencers and enclosures near the source of low frequency noise. However, in the case of tunnelling operations, design modifications to the process itself and/or to the receiver environment are not practicable leaving very little options for mitigation. One option for avoiding annoyance from low frequency noise associated with tunnelling is to temporarily provide alternate accommodation (eg hotel room) for building occupants when the source is operating within a particular distance from the building.

10.4.4.3 Low Frequency Noise Summary

The above low frequency noise assessment based on the EPA Ecoaccess Guideline includes an assessment on annoyance due to infrasound (dBG) and low frequency noise ($L_{pA,LF}$). The assessment indicates that annoyance limits will likely be exceeded during driven tunnelling works associated with the Northern Link project.

A management plan specifically for low frequency noise impacts will include, as a minimum:

- A comprehensive notification and education program to assist in allaying fears regarding tunnelling. Part of the education process will include an indication of tunnelling progress and subsequent likely (temporary) exposure periods.

- Infrasound and low frequency noise measurements in accordance with the Ecoaccess guideline at the commencement of tunnelling operations and in the event of a “low frequency” noise complaint (where required).
- An option for temporary relocation of people pending the outcome of an assessment of the impact against the EIS criteria and Ecoaccess “low frequency” noise guideline.

10.4.5 Mitigation of Vibration and Regenerated Noise from Tunnelling

The following impact management and mitigation strategies are recommended to minimise the impacts of tunnelling vibration and regenerated noise:

- Comprehensive advance notice as well as educating the public of intended tunnelling activities in the localities near the tunnel alignment. Part of the consultation process should include information regarding the monitoring program which may require involvement from residences located above the tunnel alignment. A thorough education program will assist to allay fears of the tunnelling process.
- Noise and vibration monitoring should be undertaken at the commencement of tunnelling to confirm that the source data utilised for this assessment is applicable to this project (including the low frequency noise assessment inputs and findings).
- Conduct pre- and post-blasting Building Condition Surveys in accordance with Brisbane City Council requirements where it is considered there may be potential for cosmetic (superficial) building damage from TBM and drill-and-blast methods.
- The option of temporary relocation of residents.

11. Construction Traffic

11.1 Proposed Activities

11.1.1 Spoil Removal

Spoil from the TBMs would be removed via a spoil conveyor behind the TBM in the tunnel out to the Western Connection Worksite at which point the spoil would likely be transferred to the Mt Coot-tha quarry via a surface conveyor. Spoil from the Toowong Connection will be loaded into trucks during the daytime period and transported to the Western Connection site and loaded onto the spoil conveyor. Spoil from the Kelvin Grove Connection will be loaded into trucks during the daytime and transported to the Port of Brisbane via Kelvin grove Road, ICB and Kingsford Smith Drive.

The local access arrangements, anticipated peak frequencies and total duration of spoil removal operations are summarised in **Table 66**.

▪ **Table 66 Summary of Truck and Dog Spoil Movements**

Worksite	Western Connection	Toowong Connection	Kelvin Grove Connection	ICB Connection
Local Access Rd	Western Freeway	Milton Road	Kelvin Grove Road	ICB
Hours of Spoil Removal	24 hours a day 7 days a week	Monday to Saturday, 6.30 am to 6.30 pm Saturday, no spoil removal Sunday or Public Holidays		
Peak Daily Spoil Truck Movements	Conveyor	35	40	16
Peak Hourly Night-time Spoil Truck Movements	Conveyor	0	0	0
Duration of Spoil Removal	15 months	28 months	27 months	25 months

Note: One-way volumes - total truck movements are double these values due to return trip.

11.1.2 Material and Machinery Supplies

Truck deliveries of materials and machinery would utilise the same local site access arrangements as for the spoil removal. These movements would occur during daytime working hours only, except where over-size regulations require transit at other times. Night-time deliveries have not been included as part of this assessment however an activity specific impact assessment should be carried once details are finalised.

The local access arrangements, anticipated peak frequencies and total duration of deliveries are summarised in **Table 6767**.

■ **Table 67 Summary of Material and Machinery Supply Vehicle Movements**

Worksite	Western Connection	Toowong Connection	Kelvin Grove Connection	ICB Connection
Local Access Rd	Western Freeway	Milton Road	Kelvin Grove Road	ICB
Delivery Hours	Monday to Saturday, 6.30 am to 6.30 pm Saturday, no deliveries on Sunday or Public Holidays			
Peak Daily Truck Movements	122	24	35	20
Peak Hourly Night-time Truck Movements	0	0	0	0
Duration of Spoil Removal	47 months	47 months	47 months	47 months

Note: One-way volumes - total truck movements are double these values due to return trip.

11.1.3 Employee Transport

All employee access to Northern Link worksites is directly from major roads.

11.2 Identification of Residential Areas along Spoil Routes

Residential areas along spoil routes are summarised in **Table 68**.

■ **Table 68 Residential Areas along Spoil Routes**

Spoil Source	Residential Street Frontages along Route
Western Connection Worksite	Not applicable – spoil removed from site via conveyor
Toowong Connection Worksite	Residences south of the Western Freeway eg Wool St, Elizabeth St
Kelvin Grove Worksite	Lower Clifton Terrace, Normanby Terrace and Kingsford Smith Drive
ICB Worksite	Normanby Terrace and Kingsford Smith Drive

11.3 Noise Impacts

The effect of construction-related heavy vehicle traffic on the noise emission from roadways has been assessed by calculating how the additional truck traffic would alter the LA10(12hour) level of noise emission from roadways using the CoRTN prediction algorithms. For the purpose of this analysis, the LA10(12hour) is the average LA10 traffic noise level between the hours of 6:30am and 6:30pm.

On a given roadway, the essential modelling inputs that the additional construction traffic will alter are the percentage of heavy vehicles and total vehicle numbers utilising that roadway. For the assessment of typical construction truck volumes, the peak daily frequencies have been adopted as being representative of total truck movements. This assessment is summarised in **Table 69**.

For this analysis the existing AADT road traffic predictions an all roads has been obtained from traffic information supplied by the BCC.

Table 69 Effect of Construction Truck Movements on Traffic Noise Levels along Spoil Routes - $L_{A10(18hour)}$

Roadway	Road Section	Change in LA10(18hour) Traffic Noise Level (dBA)
Mt Coot-tha Road	Western Fwy – Frederick St	+ 0.1
Western Freeway	West of Mt Coot-tha Rd	+ 0.1
Milton Rd	Gregory St – Mt Coot-tha Rd	+ 0.2
Kelvin Grove Road	ICB – Victoria St	+ 0.2
ICB	Kelvin Grove Rd – Kingsford Smith Dr	+ 0.2
Kingsford Smith Drv	ICB – Gateway Mwy	+ 0.1

From this analysis it can be seen that spoil traffic would not increase average traffic noise levels on spoil routes by more than 0.2 dBA for existing significant road corridors. It should be noted that the increase for Mt Coot-tha Road is based on material deliveries (eg concrete) to the Western Connection Worksite and therefore the increase is representative of the section of the road immediately adjacent to the Western Freeway. It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear and therefore negligible.

The absolute maximum noise levels associated with vehicle pass-bys would not be altered by Northern Link construction vehicles (see recommendation below for all Northern Link haul trucks to be tested against ADR 28/01), however, the frequency of such events would increase.

It is concluded that spoil traffic would not significantly impact on the noise environment of residential locations along the spoil routes that have been assessed. Best practice noise management practices that should be incorporated into management of spoil removal as required by the General Environmental Duty under the Environmental Protection Act 1994. These measures are discussed in the following section.

11.3.1.1 Mitigation

Recommended mitigation measures include:

- Best practice management over engine noise emissions by procurement and maintenance of a fleet that conforms to Australian Design Rule 28/01 for engine noise emissions, tested in accordance with the National Road Transport Commission document Stationary Exhaust Noise Test Procedures for In-Service Motor Vehicles.
- Adoption of airbag suspension throughout the fleet to minimise noise associated with empty trucks travelling over road irregularities.
- Satellite tracking and management of the position of the truck fleet to ensure that waiting queues are appropriate to space constraints, minimising noise from idling trucks.

11.4 Vibration Impacts

Fully loaded trucks travelling on properly maintained public roadways would not generate significant levels of ground vibration at buildings adjacent to spoil routes.

12. Health Effects Due to Construction Noise and Vibration

12.1 Noise

Community noise or environmental noise is defined by the World Health Organisation (WHO) as noise emitted from all sources (except noise at the industrial workplace) including road, rail, air traffic, construction, public works and the neighbourhood. The WHO's *Guidelines for Community Noise* lists the major health effects as:

- Noise-induced hearing impairment
- Interference with speech communication
- Disturbance of rest and sleep
- Psychophysiological, mental-health and performance effects
- Effects on residential behaviour and annoyance, and
- Interference with intended activities.

Until recently, construction noise has been largely viewed as an amenity issue and rarely focussed on significant public health issues. Traditional environmental impact statements prepared for major infrastructure projects often include assessment of noise impacts as assessed against particular State or local planning guidelines. A recommendation of the federal government's enHealth report *The health effects of environmental noise* is that impact statements include assessment of health end-points such as sleep disturbance, interference with speech and communication, annoyance and hearing impairments, noting that further research is required to provide a better insight into the relationship between noise and sensitive populations.

The following sections include a discussion on the issues of health effects relating specifically to annoyance, hearing impairment and sleep disturbance, associated with the Northern Link Project.

12.1.1 Annoyance

The most common subjective response to noise is annoyance which may include mild anger and fear which stems from a belief that one is being avoidably harmed. The level of 'annoyance' experienced by one person may differ considerably to another individual due to many factors including personal characteristics (eg people who are already stressed) and the ability to control the living environment.

As construction works associated with the Northern Link Project will occur in proximity to noise sensitive receivers it is inevitable that some people may experience annoyance as a result of the project. As reported by the WHO, people may even report feeling anger, disappointment, dissatisfaction, withdrawal, helplessness, depression and anxiety. It is therefore imperative that construction noise be minimised insofar as possible through best practice measures, the community be kept informed of construction works in advance and that any complaints are promptly addressed.

12.1.2 Hearing Impairment

Hearing impairment can be defined as an increase in the threshold of hearing. In terms of environmental noise, hearing impairment can result from exposure to very high levels of noise of short duration or moderately loud noise over longer durations. The obvious consequence of hearing impairment is the inability to understand speech which can have a significant effect on a person's quality of life.

The first morphological changes after noise exposure are usually found in the inner and outer hair cells of the cochlea where the stereocilia become fused and bent. After more prolonged exposure the outer and inner hair cells related to transmission of high-frequency sounds are missing.

The WHO recognises that in developing countries, not only occupational noise but also environmental noise is an increasing risk factor for hearing impairment. The WHO Guidelines for Community Noise suggest that the risk for hearing impairment from any noise source would be negligible for LAeq, 24hr values of 70 dBA over a lifetime. $L_{Aeq,24hr}$ values of 70 dBA are very unlikely to occur at any stage during construction of the Northern Link Project.

To avoid hearing impairment, impulse noise exposures should never exceed 140 dB peak sound pressure in adults and 120 dB peak sound pressure in children. The only activity during construction of the Northern Link that has the potential to exceed this limit is blasting. Impacts associated with Northern Link blasting will be addressed in the Blast Management Plan and include detailed mitigation measures, for example provision of an acoustic enclosure, to prevent exceedances above the recommended limits for adults and children.

12.1.3 Sleep Disturbance

The issue of sleep disturbance in terms of quantifying acceptable limits is discussed in **Section 2.2.2**. Out of hours Northern Link construction works have been assessed throughout this report in terms of sleep disturbance impacts.

Potential for sleep disturbance resulting from Northern Link construction works have been identified. The consequences of sleep disturbance can be awakenings and alterations of sleep stages (categorised as 1, 2, 3, 4 and REM), difficulty falling asleep, changes in respiration, cardiovascular effects and increased body movements. These changes can affect mood and performance during the following day.

As sleep is critical to restore biological processes, all practicable mitigation measures are required to minimise potential for sleep disturbance during out of hours Northern Link construction works.

12.2 Vibration

The key issues having potential to affect the health and wellbeing of receivers exposed to Northern Link vibration are annoyance, sleep disturbance and whole body vibration exposure. Most research to date focuses on health effects associated with occupational vibration exposure such as back pain.

The following sections include a brief discussion of the health issues relating to vibration from construction.

12.2.1 Annoyance

Like noise, annoyance resulting from vibration exposure can vary from person to person and in severe cases can lead to feelings similar to that experienced by people annoyed from noise. Some particularly sensitive people may become annoyed when exposed to vibration levels slightly above the threshold of perception. Annoyance can often stem from a feeling of fear and anxiety particularly if the individual is concerned about the potential for damage to property from the vibration.

The AS 2670 human comfort criteria (discussed in **Section 2.3.4.2**) applied to the Northern Link Project aims to avoid annoyance to receivers. However the vibration assessment in **Section 10.3** indicates that the human comfort limits may at times be exceeded. Subsequently it is important that construction vibration be minimised insofar as possible through best practice measures, the community be kept informed of construction works in advance, particularly tunnelling progress, and that any complaints are promptly addressed.

12.2.2 Sleep Disturbance

As discussed in **Section 2.3.4.3**, the recommended guide level established for the Northern Link Project to avoid sleep disturbance is 0.5 mm/s (peak) based on experience of human perception levels and various vibration standards. Some people may be comfortable with much higher levels of night vibration than the 0.5 mm/s guide level.

Vibration levels have been predicted for tunnelling operations between portals (refer to **Section 10**) and have been assessed against the sleep disturbance guide level. In some areas above the Northern Link tunnels, the sleep disturbance guide level is predicted to be exceeded which indicates that sleep disturbance may result.

12.2.3 Whole Body Vibration

Health effects from vibration can be divided into intensity dependent and frequency dependent effects.

Intensity dependent effects cause damage to body organs from high vibration exposure levels at relatively low frequencies. Vibrations at lower acceleration levels are blamed for causing fatigue failures of different compound structures of the spine, interference with the nutrition of the discs and as such predisposing them to degradation. These effects fall in the area of human vibration termed Whole Body Vibration (WBV). WBV is assessed using an orthogonal direction system, i.e. vibration in the forward-aft direction (x), the side-to-side direction (y) and the up-down direction (z). For health effects, the frequencies of interest are in the 1 to 80Hz range transmitted to the seated body.

Frequency dependent effects occur normally after prolonged exposures to the higher vibration frequency ranges such as from hand held power tools.

Vibration from tunnelling activities will occur at frequencies below 200 Hz and therefore any potential health impacts would result from high vibration levels at relatively low frequencies; hence an assessment of WBV is required.

The current Australian standard is AS 2670.1-2001 "*Evaluation of human exposure to whole-body vibration*".

AS 2670.1-2001 distinguishes three main criteria which can be used to assess vibration and their effects on humans:

- Health effects; from periodic, random and transient vibration on the health of workers exposed to whole body vibration during travel, at work or during leisure activities;
- Comfort and perception; estimation of the effect of vibration on the comfort of persons who are exposed to whole-body vibration during travel, at work or during leisure activities; and
- Motion sickness; the effects of oscillatory motion on the incidence of motion sickness.

Annexure B of AS 2670.1-2001 "*Guide to the effects of vibration on health*" provides guidance for the assessment of WBV with respect to health. It applies to people in **normal health** who are **regularly exposed** to vibration. Biodynamic research and epidemiologic studies have suggested evidence for an elevated health risk due to long term exposure with high intensity, low frequency WBV. Typically the lumbar spine and connected nervous system are affected.

Figure B.1 of Annexure B of AS 2670.1-2001 (refer to **Figure 12**) provides three (3) health guidance caution zones.

Figure 12 Health Guidance Caution Zones.

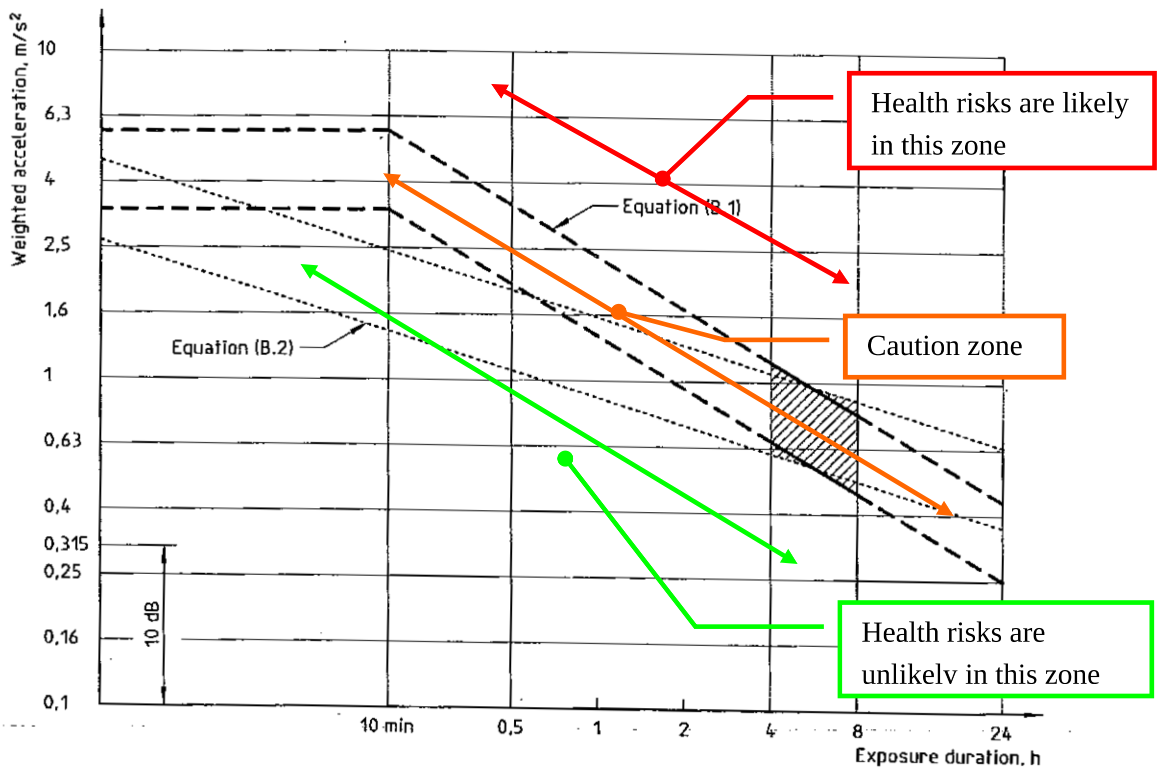


Figure B.1 — Health guidance caution zones

From, it is clear that weighted acceleration levels less than 0.25 m/s^2 are unlikely to pose a health risk for any duration. Equivalent Peak Particle Velocity (PPV) values can be calculated for various possible principal frequencies from 10 Hz to 200 Hz (as these are expected frequencies of tunnelling activities. As the exact frequency of tunnelling is unknown (it will change depending on a number of site dependant variables and will be time variant), a sensitivity analysis was carried out. The conservative approach of assuming that all the vibration occurred in the vertical direction resulted in the lowest PPV value at which the weighted acceleration level of 0.25 m/s^2 was reached. **Table 70** shows the resulting equivalent PPV for a range of principal frequencies.

Table 70 Equivalent PPV for frequencies

Principal Frequency (Hz)	AS2670 weighting factor (vertical)	Health risk weighted vibration level (m/s2)	Equivalent PPV (mm/s)
5	1.0390	0.25	48
10	0.9880	0.25	25
20	0.6360	0.25	20
40	0.3140	0.25	20
80	0.1320	0.25	24
125	0.0540	0.25	37
160	0.0285	0.25	55
200	0.0152	0.25	82

Clearly expected vibration levels will be much lower than the calculated equivalent PPV where health risks may become an issue; therefore the health risk associated with generated vibration levels during construction may be considered extremely low.

12.2.4 Asbestos

Potential mechanisms for dislodging asbestos fibres due to construction vibration are:

- **Sheeting cracking and being damaged by vibration, leading to the generation of fine asbestos particles.**

  The project vibration goals and the Environmental Protection Regulation 1998 blasting limits are set at levels below which any form of damage (even cosmetic) would occur to buildings. Provided construction vibration levels are managed in accordance with the recommendations contained in this report and the EPA's Environmental Protection Regulation 1998, no cracking or damage to asbestos sheeting is expected, therefore there are no asbestos concerns.

- **Vibration producing movement between abutting sheets leading to the generation of fine asbestos particles.**

  Based on the EPA's 25 mm/s limit for blasting (blasting is the highest level of vibration anticipated for the project), a typical blast frequency (around 35 Hz) and 2 sheets moving in opposite directions, movement in the order of 200 microns would result. This scale of movement is considered too small to cause asbestos fibres to be released from two abutting sheets rubbing together.

- **Vibration causing (settled) asbestos dust within the ceiling cavity to become dislodged and fall through cracks, vents, light fittings or other openings.**

  Low levels of vibration of around 0.5 mm/s are commonly associated with visible movement of susceptible contents within a building and vibration of this magnitude is therefore considered capable of disturbing settled dust. In the absence of literature on this topic, the recommended worst case scenario is that perceptible levels of vibration (0.5 mm/s and greater) should be considered capable of dislodging settled asbestos dust. Accordingly, management techniques are recommended (where appropriate) as follows:

  - pre-construction inspections
  - pre-construction sampling of dust for identification of asbestos (where required)
  - removal of dust containing asbestos by licensed removalists
  - plastic sheeting installed in ceilings to collect dust
  - post-construction clearance inspections and associated sampling

  These measures should form part of the Construction Noise and Vibration Environmental Management Plan.

13. Construction Monitoring Program

13.1 Introduction

Construction noise and vibration monitoring procedures will be developed to address the initial and ongoing monitoring of emissions from construction to assist in planning of excavation and construction works. This will be of particular importance where work activities are close, that is, less than 100 m to residences or other noise sensitive receivers.

Pre-condition surveys will likely be conducted for buildings and historical items (eg Toowong Cemetery) in vibration-sensitive zones prior to commencement of construction.

Ongoing spot checks of noise intensive plant and equipment will be undertaken. Construction noise and vibration levels will be monitored throughout the construction phase to verify compliance with the design goals. Monitoring will be undertaken at those locations where predictions indicate exceedance of the nominated project noise design goals and vibration criteria. Supplementary noise and/or vibration monitoring may also be conducted to identify issues of concern in response to any complaints.

Weekly inspections will be undertaken throughout the construction period by the Site Environment Officers, the Site Supervisor or Project Engineers. These inspections will ensure that appropriate noise and vibration controls are being implemented and are effective. It will also ensure that where necessary additional monitoring is undertaken as a result of changes to activities/construction methods and community complaints. Any issues identified during the weekly inspections will be documented in regular (typically monthly) monitoring reports.

The actual monitoring program will be refined closer to the commencement of construction as part of the tendering and detailed design processes. The following outlines a construction monitoring program which is recommended as a minimum for the Northern Link Project.

13.2 Construction Noise Monitoring Program

Noise monitoring recommendations for the Northern Link Project are summarised in Error! Reference source not found.. Prior to any monitoring being undertaken, the noise monitoring equipment should be calibrated in accordance with the manufacturer's guidelines and meet AS1055 requirements for environmental monitoring.

Table 71 Construction Noise Monitoring Recommendations

Monitoring	Schedule	Locations	Procedures and Instrumentation
Operator Attended Noise Monitoring - Worksites and Road Surface Works	At the commencement of all noise intensive construction activities then typically once a week thereafter.	Typically at the nearest receiver in each direction to each site specific activity associated with: - Worksite activities (site prep works, day and night tunnelling). - Road surface works	Attended measurements to quantify and qualify construction noise emissions using a calibrated sound level meter capable of measuring LA90, LAeq, LA10 and LA1 statistical noise levels in 15 minute intervals. One 15 minute sample per survey location is generally sufficient. Extraneous noise (eg cars, trains etc) should be excluded from the measurements. Sources contributing to the noise levels are to be noted.
Unattended Noise Monitoring - Worksites	On a continuous basis or as required. Regular (typically weekly or fortnightly) data downloads would be required.	Continuous noise logging to be undertaken at the nearest noise sensitive receiver adjacent to tunnel worksites taking into consideration extraneous noise sources such as major roads..	A calibrated noise logger capable of measuring LA90, LAeq, LA10 and LA1 statistical noise levels in 15 minute intervals would be sufficient. Noise loggers are not typically used where extraneous noise is present. Therefore consideration should be given to using noise loggers capable of recording audio samples by means of preset trigger level exceedances to assist in identifying the source of the noise level exceedance.
Plant Noise Audits	As required but generally limited to particularly noisy plant items such as piling rigs, hydraulic hammer, haul trucks etc.	On site, typically at 7 m from the item of plant (for surface equipment) in the direction of dominant noise emission. Closer to the source if other sources prevent measurement at this distance.	Attended measurements using a calibrated sound level meter capable of measuring LAeq, LA10, LA1 and LAmax statistical noise levels. Select the items of plant which appear to be the most dominant sources of noise. Measure noise emissions under conditions of maximum noise normally occurring for that source. For most noise sources, a one minute sample will be satisfactory, although sampling may be extended up to 15 minutes for sources varying greatly over time. The results of the plant noise audits would enhance the input data fed into the predictive modelling process. Equipment significantly exceeding the plant noise levels used in the predictive modelling should undergo inspection to identify appropriate noise control measures. Where noise control measures are not feasible, predictive modelling should be updated accordingly and additional mitigation measures adopted where required. Haul trucks to be checked against ADR 28/01 before commencing works and at 12 month intervals.
Regenerated Noise Monitoring	At the commencement of driven tunnelling works at each tunnel face.	10 receiver locations per working face of short-term operator attended regenerated noise measurements at varying slant distances from the working face.	A calibrated sound level meter capable of measuring LA90, LAeq, LA10, LA1 and LAmax statistical noise levels and one-third octave noise levels in 15 minute intervals would be sufficient The results of the regenerated noise measurements would enhance the input data fed into the predictive modelling process.
Response to Complaints	Within a 24 hour period of receiving the complaint	As appropriate to address the particular complaint.	Attended or unattended measurements as appropriate to identify and measure the source in question.

13.3 Construction Vibration Monitoring Program

Vibration monitoring recommendations for the Northern Link Project are summarised in Error! Reference source not found..

Table 72 Construction Vibration Monitoring Recommendations

Monitoring	Schedule	Locations	Procedures and Instrumentation
Driven Tunnelling	A minimum of 1 vibration logger per working face for first 3 months for each tunnel section. After initial 3 months at each section, a minimum of 1 vibration logger for each tunnel section where: - exceedance of vibration goals are predicted. - complaints have been received (to be addressed within a 24 hour period).	Tunnel sections include: - 2 x mainline tunnels - 2 x Toowong connection tunnels - 2 x Kelvin Grove connection tunnels At the nearest receiver to the cutting face where predictions indicate exceedances. As appropriate to address the particular complaint.	Operator attended measurements using a calibrated instrument capable of measuring peak particle velocity in 3 axes (ie vertical, longitudinal and transverse). The results of the vibration monitoring would enhance the input data fed into the predictive modelling process.
Blasting	A minimum of 2 vibration and blast overpressure monitoring locations during each blast throughout the blasting phase of the project.	All efforts should be made to locate the monitors at the nearest receivers to the blast site. Monitoring should always be undertaken a heritage listed structure if close to blasting	Measurements using a calibrated instrument capable of measuring peak particle velocity in 3 axes (ie vertical, longitudinal and transverse) and blast overpressure. The results of the blast monitoring would enhance the input data fed into the predictive modelling process.
Buffer Distance Tests for: - Worksite activities - Surface road works	-At the commencement of all vibration intensive activities associated with each worksite and surface road works. To address complaints (within 24 hours) Where exceedances are predicted to occur.	At foundation of potentially affected structure	Attended measurements using a calibrated instrument capable of measuring peak particle velocity in 3 axes.

Prior to any vibration monitoring being undertaken the monitoring equipment will be calibrated in accordance with the manufacturers guidelines.

14. Conclusions

14.1 General

This analysis of noise and vibration impacts associated with the Northern Link project has been prepared based on a number of design parameters as supplied by the JV. The analysis is intended to provide a practical and specific understanding of the potential impacts, and the mitigation measures that may be necessary to mitigate any impacts during the construction phase.

It is anticipated that the construction methodology will evolve and be refined as detailed construction plans are developed for the project, with consequential implications for the design of mitigation strategies. It is therefore recommended that a detailed Construction Noise and Vibration Management Plan (or sub-plans) be prepared for the project as the detailed construction plans are developed.

14.2 Recommended Noise and Vibration Targets for Mitigation Design

The objective for the management of construction noise and vibration is to maintain a reasonable noise and vibration environment within sensitive properties for the duration of the project.

The following definitions of 'reasonable' construction noise and vibration are recommended for the purpose of guiding the development of detailed design of mitigation strategies for this project and to provide guidance for establishing a compliance framework for licensing purposes.

14.2.1 'Reasonable' Construction Noise

The recommended definition of 'reasonable' construction noise for the purpose of detailed development of mitigation strategies for this project is as follows:-

- For the daytime, adoption of "maximum" internal design levels advised in AS/NZS 2107:2000 as non-binding noise targets for steady and quasi-steady sources of construction noise assessed by a $L_{Aeq(15minute)}$ parameter (e.g. rock-drill, excavator, bulldozer), with a tolerance of 10 dB above these levels for the $L_{A10(15minute)}$ parameter to control non-steady sources of construction noise (e.g. rock-hammer, pile-driver).
- For long-term evening and night-time noise sources (e.g. ventilation plant, and 24 hour spoil handling systems), 'reasonable' noise levels would be:
    - For transient noises, the recommended internal sleep disturbance criteria for L_{Amax} levels of 45dBA/50dBA as advised in NIAPSP (refer to **Section 2.2.1**).
    - for steady noises, "satisfactory"[17] internal design levels advised in AS/NZS 2107:2000, or imission levels not greater than the external background noise level (L_{A90}), whichever is lower, with imission assessed using an $L_{Aeq,adj}$[18] $_{(15minute)}$ parameter.
    - These targets should be treated as binding.

[17] "satisfactory" noise level recommendations in AS2107 are generally 10 dBA lower, or more stringent, than "maximum" recommendations.
[18] Adjusted for intrusive tonal or impulsive characteristics in accordance with AS1055 Part 1.

- For temporary evening and night-time noise sources (e.g. regenerated noise during the underground passby of tunnelling machinery), ‘reasonable’ noise levels would be:
  - For transient noises, the recommended internal sleep disturbance criteria for L_{Amax} levels of 45dBA/50dBA as advised in NIAPSP, and
  - For steady noises, “maximum” internal design levels advised in AS/NZS 2107:2000 assessed by an $L_{Aeq(15minute)}$ parameter; and
  - These targets should also be treated as binding.

14.2.2 ‘Reasonable’ Construction Vibration

The definition of ‘reasonable’ construction vibration for the purpose of detailed development of vibration mitigation strategies for this project is as follows:-

- For the daytime, statutory vibration limits for blasting, and the recommended vibration guide values for other extraction methods as summarised in **Table 5** based on daytime transient vibration criteria for “low probability of reaction” derived from AS2670:1990.
- For night-time human comfort, recommended ‘reasonable’ vibration levels would be up to 0.5 mm/s (peak).

14.3 Preparation and Operation of Worksites

14.3.1 Western Connection Worksite (WS1)

The most significant potential noise issues at the western connection worksite (WS1) are initial daytime earthworks which at times is likely to include rockbreaking activities. Construction impacts have been identified for residents south of the Western Freeway based on comparison with the noise goals.

After the completion of the initial earthworks at the western connection worksite (approximately 2 weeks), ongoing construction activities associated with daytime and night-time tunnelling support is predicted to comply with the relevant noise goals with the exception of a marginal 2 dBA exceedance due to the spoil conveyor. No site specific noise mitigation other than the acoustic enclosure over the eastbound portal or cut and cover enclosure is therefore required.

14.3.2 Toowong Connection Worksite (WS2)

The most significant potential noise issues at the Toowong connection worksite (WS2) is the daytime demolition of existing buildings, earthworks and delivery/spoil vehicles on the site. At the adjoining residences in Valentine Street, the noise from rockbreakers and other plant items will significantly exceed the design goal and is likely to result in significant acoustical impacts (eg interference with passive listening, resting and conversation) given the construction noise levels are noticeably above the prevailing levels of road traffic noise from Milton Road and Frederick Street. Noise mitigation should be further examined to maintain a reasonable noise environment at these residential locations (refer to **Section 14.3.4**).

14.3.3 Kelvin Grove Connection Worksite (WS3)

The most significant potential noise issues at the Kelvin Grove connection worksite (WS3) is the daytime demolition of existing buildings, earthworks and delivery/spoil vehicles on the site. At the adjoining residences in Lower Clifton Terrace, Upper Clifton Terrace and Westbury Street, the noise from rockbreakers and other plant items will significantly exceed the design goals and is likely to result in significant acoustical impacts (eg interference with passive listening, resting and conversation) given the construction noise levels are noticeably above the prevailing levels of road traffic noise from Kelvin Grove Road and the ICB. Noise mitigation should be further examined to maintain a reasonable noise environment at these residential locations (refer to **Section 14.3.4**).

Further construction noise and vibration investigations are recommended for QUT's proposed Recording Studio once plans are available, QUT's Institute of Health and Biomedical Innovation should vibration sensitive equipment be identified within this facility and the Red Cross's Processing Facility when "limit/criteria" specifications for their identified vibration sensitive equipment are made available.

14.3.4 Noise Mitigation for Worksites

The following noise control measures are recommended for noise mitigation at worksites:

- Provide advance notification of the time, type and duration of noise intensive works.
- Where feasible, install (temporary) noise screens to reduce demolition and earthmoving noise during "Site Preparation" at property boundaries of residences adjacent to the Toowong and Kelvin Grove worksites. These screens need to be carefully designed to be effective and are likely to require a minimum of 5 m in height to provide a benefit for adjacent highest buildings. As an alternative, consideration could be given to upgrading the façade windows, and provision of air-conditioning to the affected residents, where it proves cost effective and acceptable to the community.
- Use localised (ie close to noise source) noise screens for particularly noisy operations such as rockdrilling and rockbreaking.
- Select plant and processes which minimise source noise levels
- Construction of a 'high' performance acoustic enclosure over the portal and stockpile area for the Toowong and Kelvin Grove worksites, with indicative acoustic performance as shown in **Table 21** (subject to detailed design).
- Construction of a 'low' performance acoustic enclosure over the eastbound portal for the western connection worksite, with indicative acoustic performance as shown in **Table 21** (subject to detailed design).
- The movement of trucks within the worksite should be designed to limit (as much as possible) the need for reversing and therefore reversing alarms. Where issues with reversing alarms occur, consideration should be given to the use of broadband "buzzer" reversing alarms and/or alarms which actively vary their volume according to the ambient noise levels during activation - rather than constant volume (tonal) "beeping" alarms.

- Design of continuously operating ventilation plant and any other plant that operates at night to meet 'reasonable' night-time noise objectives as defined in **Section 2.2.2**.
- Continuous monitoring of noise levels from variable noise sources (e.g. rockbreaking and rock-drill noise) at worksites to ensure that such activities meet the 'reasonable' levels as defined in **Section 2.2.2**.

14.3.5 Vibration

To minimise vibration impacts for all worksites, it is recommended:

- Specific advance notification of any vibration intensive activities such as vibratory rolling for general earthworks or night-time road construction activities.
- Monitoring of vibration on structures and inside habitable areas due to vibratory rolling that occurs within a nominal distance of 25 m.

14.4 Surface Construction of Roadways

14.4.1 Western Connection

The daytime construction of the cut and cover and transition structures is predicted to result in exceedances of the noise goal. Small exceedances (ie up to 4 dBA) above the night-time noise goal are also predicted for nearest Wool Street receivers during road realignment works involving asphalt plant. Noise monitoring is recommended to confirm predictions and assess any further need for specific noise mitigation.

14.4.2 Toowong Connection

The daytime and night-time construction of the elevated structures and road realignment works for Valentine Street and Milton Road residences are likely to be found intrusive (up to 29 dBA above the noise goals) and in the case of the night-time work may result in sleep disturbance. Consequently, noise mitigation should be examined so as to maintain a reasonable noise environment at these residences.

The following mitigation measures are recommended for further consideration guided by the 'reasonable' noise objectives for construction noise:

- Provide advance notification of the time, type and duration of works.
- Insofar as possible schedule noise intensive works during the daytime period.
- Where night-time works are required for public safety reasons such as lifting bridge segments over Milton Road, schedule the noisiest stage of the works outside of the quietest period of the night (typically 1am to 3am).
- Plan the work so as to take advantage of shielding from buildings, approach ramps, stationary plant etc.
- If required, assist owners of properties adjacent to the work areas to temporarily upgrade the acoustical insulation and ventilation of rooms facing the worksite to address noise.

- Continuous monitoring of Northern Link construction noise levels to ensure that such activities meet the 'reasonable' levels as defined in **Section 2.2.2** or to aid in the development of specific noise mitigation measures.
- Early construction of the operational noise barriers north and south of Milton Road to protect residences during the construction period.

14.4.3 Kelvin Grove Connection

The highest potential for impacts at residential locations occurs during the construction of the cut and cover and transition areas on and near Kelvin Grove Road, where the construction noise levels are predicted to significantly exceed the noise goals by as much as 22 dBA. This level of construction noise would likely be found to be intrusive and result in an acoustic impact on the residences (eg night-time sleep disturbance, interference with passive listening, resting and conversation).

The following noise control measures are recommended for Kelvin Grove surface connection works guided by the 'reasonable' noise objectives:

- Advance notification of the time, type and duration of works, especially any night works.
- Select construction processes and plant to minimise construction noise.
- Insofar as possible schedule noise intensive works during the daytime period.
- Assist owners of properties nearest the construction site to temporarily upgrade the acoustical insulation and ventilation of rooms facing the construction area.
- Continuous monitoring of Northern Link construction noise levels to ensure that such activities meet the 'reasonable' levels as defined in **Section 2.2.2** or to aid in the development of specific noise mitigation measures.
- Early construction of the operational noise barriers west of Kelvin Grove Road to protect residences during the construction period, or erect temporary construction noise barriers in a similar location.

14.4.4 ICB Connection

The highest potential for impacts at residential locations occurs during the construction of the cut and cover and transition structures along the ICB, where the construction noise levels are predicted to exceed the night-time LAeq(15minutes) noise goal by up to 13 dBA and the daytime LAeq(15minutes) noise goal by up to 16 dBA. This level of construction noise would likely be found to be intrusive and result in an acoustic impact on the residences (eg interference with sleeping, passive listening, resting and conversation).

Northern Link construction noise may have the potential to be audible inside the nearest classrooms at Brisbane Grammar School and Brisbane Girls Grammar School on the basis of the predicted levels however it is recommended that a detailed investigation of the nearest school buildings to the work be carried out to determine the degree of façade attenuation.

The following noise control measures are recommended for mitigation of noise likely to result from ICB connection road works, guided by the 'reasonable' noise objectives:

- Provide advance notification of the time, type and duration of works, especially any night works.
- Select construction processes and plant to minimise construction noise.
- Assist owners of properties nearest the construction site to temporarily upgrade the acoustical insulation and ventilation of rooms facing the construction area.
- A detailed investigation of classroom facades at Brisbane Grammar and Brisbane Girls Grammar Schools to determine actual noise attenuation and therefore assess the need for further mitigation.
- Continuous monitoring of Northern Link construction noise levels to ensure that such activities meet the ‘reasonable’ levels as defined in **Section 2.2.2** or to aid in the development of specific noise mitigation measures.
- Early construction of the operational noise barriers to protect Normanby Terrace residences during the construction period, or erect temporary construction noise barriers in a similar location.

14.5 Underground Tunnelling Between Portals

14.5.1 Roadheading

Predicted worst-case regenerated noise levels from roadheading exceed the AS2107 guide values for many residential receivers above the roadheader driven sections of the Northern Link tunnels (refer to **Table 61** for location details). Sleep disturbance impacts are also likely to result from Northern Link on/off ramp tunnelling due to the shallow tunnel depths. All practicable mitigation measures will be required to minimise the impact from these works.

There are shallow tunnel areas at both the Toowong (on and off ramps) and Kelvin Grove (off ramp only) areas where vibration from roadheaders may be perceptible (refer to Table 56 for location details). No major on-going vibration mitigation measures or impact response management procedures are anticipated to be necessary for this type of tunnelling. It is recommended however that vibration measurements/monitoring be conducted during the start of the tunnelling works to confirm the predictions (based on the actual plant items being used) and to allay any concerns that the community may express.

14.5.2 Blasting

Only daytime blasting is envisaged for the project. Blasting generally results in short, strongly noticeable vibration lasting one to two seconds. The normal mitigation method in relation to human impacts is to give clear and concise pre-notification to all persons in the affected area.

Careful blast design is recommended to mitigate against building impacts, and if necessary, using gradually increasing trial blasts to establish safe design parameters. It is a requirement of Brisbane City Council to conduct pre- and post-blasting Building Condition Surveys where it is considered there may be potential for cosmetic building damage.

14.5.3 Tunnel Boring Machine

Worst-case predictions indicate that it is likely that regenerated noise from the TBM will be noticeable in many buildings above the tunnel alignment and may result in sleep disturbance (refer to

Tables 59 and 60 for location details). All practicable mitigation measures detailed in **Section 10.4.5** are required to minimise the impact from these works.

Regarding vibration, sleep disturbance may result if the vibration levels from a continuous source are higher than 0.5 mm/s which is predicted to be the case for many residences above the mainline tunnels. It should be noted that the 0.5 mm/s night-time guideline vibration level for this project is conservatively low and some people may be comfortable with higher levels.

As indicated by the levels in **Table 54** and **Table 55**, vibration from the TBMs may potentially exceed the “damage” guide values at the Toowong Cemetery, the Charlotte Street area and the Normanby Terrace area. Building condition surveys should be conducted prior to the tunnelling works and monitoring during the works will be required.

14.5.4 Low Frequency Noise Assessment

Initial investigations into potential low frequency noise from tunnelling operations indicate that annoyance may result from infrasound (< 20 Hz) associated with TBM tunnelling within 10 m from a residential dwelling. Also, low frequency noise levels will potentially exceed the acceptable limits associated with perception and annoyance for all receiver types prescribed in the Queensland EPA’s Ecoaccess guideline.

It is recommended that a detailed low frequency noise assessment be carried out for the Northern Link Project as additional data becomes available, for example, data obtained from measurements carried out within a typical residential dwelling and at similar slant distances to the Northern Link tunnel.

14.5.5 Asbestos

Potential mechanisms for dislodging asbestos fibres due to construction vibration are:

- *Sheeting cracking and being damaged by vibration, leading to the generation of fine asbestos particles.*

  The project vibration goals and the Environmental Protection Regulation 1998 blasting limits are set at levels below which any form of damage (even cosmetic) would occur to buildings. Provided construction vibration levels are managed in accordance with the recommendations contained in this report there are no asbestos concerns.

- *Vibration producing movement between abutting sheets leading to the generation of fine asbestos particles.*

  The scale of movement (200 microns) anticipated for blasting is considered too small to cause asbestos fibres to be released from two abutting sheets rubbing together, there are no asbestos concerns.

- *Vibration causing (settled) asbestos dust within the ceiling cavity to become dislodged and fall through cracks, vents, light fittings or other openings.*

Low levels of vibration of around 0.5 mm/s are commonly associated with visible movement of susceptible contents within a building and vibration of this magnitude is therefore considered capable of disturbing settled dust. In the absence of literature on this topic, the recommended worst case scenario is that perceptible levels of vibration (0.5 mm/s and greater) should be considered capable of dislodging settled asbestos dust. Accordingly, management techniques are recommended (where appropriate) as follows:

- pre-construction inspections
- pre-construction sampling of dust for identification of asbestos (where required)
- removal of dust containing asbestos by licensed removalists
- plastic sheeting installed in ceilings to collect dust
- post-construction clearance inspections and associated sampling

These measures should form part of the Construction Noise and Vibration Environmental Management Plan.

14.5.6 Recommended Mitigation for Tunnelling Vibration and Regenerated Noise

The following impact management and mitigation strategies are recommended to minimise the effects of tunnelling vibration and regenerated noise:

- Comprehensive advance notice of intended tunnelling activities in the localities near the tunnel alignment. Notification will include Northern Link contact details for residents to communicate concerns and/or complaints that may arise from the works.
- Noise and vibration monitoring should be undertaken at the commencement of roadheader, EPB tunnelling and blasting to confirm that the source data utilised for this assessment is applicable to this project.
- Conduct night-time tunnelling subject to compliance with ‘reasonable’ night-time vibration and regenerated noise levels as defined in **Section 2.2.2**.
- Conduct pre- and post-blasting Building Condition Surveys in accordance with Brisbane City Council requirements where it is considered there may be potential for cosmetic (superficial) building damage from drill-and-blast methods.
- The option of temporary relocation of residents.

14.6 Construction Traffic

Spoil traffic would not increase average traffic noise levels on spoil routes by more than 0.2 dBA for existing significant road corridors. It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear and therefore negligible.

It is concluded that spoil traffic would not significantly impact on the noise environment of residential locations along the spoil routes that have been assessed.

14.6.1 Recommended Construction Traffic Mitigation Measures

Recommended construction traffic mitigation measures for Northern Link include:

- Best practice management over engine noise emissions by procurement and maintenance of a fleet that conforms to Australian Design Rule 28/01 for engine noise emissions, tested in accordance with the National Road Transport Commission document Stationary Exhaust Noise Test Procedures for In-Service Motor Vehicles.
- Adoption of airbag suspension throughout the fleet to minimise noise associated with empty trucks travelling over road irregularities.
- Satellite tracking and management of the position of the truck fleet to ensure that waiting queues are appropriate to space constraints, minimising noise from idling trucks.

14.7 Health Effects

14.7.1 Construction Noise

As construction works associated with the Northern Link Project will occur in proximity to noise sensitive receivers it is inevitable that some people may experience annoyance as a result of the project. It is therefore imperative that construction noise be minimised insofar as possible through best practice measures, the community be kept informed of construction works in advance and that any complaints are promptly addressed.

The WHO Guidelines for Community Noise suggest that the risk for hearing impairment from any noise source would be negligible for $L_{Aeq, 24hr}$ values of 70 dBA over a lifetime. $L_{Aeq,24hr}$ values of 70 dBA are very unlikely to occur at any stage during construction of the Northern Link Project.

To avoid hearing impairment, impulse noise exposures should never exceed 140 dB peak sound pressure in adults and 120 dB peak sound pressure in children. The only activity during construction of the Northern Link that has the potential to exceed this limit is blasting.

Potential for sleep disturbance resulting from Northern Link construction works have been identified. As sleep is critical to restore biological processes, all practicable mitigation measures are required to minimise potential for sleep disturbance during out of hours Northern Link construction work.

14.7.2 Construction Vibration

The vibration assessment indicates that the human comfort limits (AS 2670) may at times be exceeded. Subsequently, it is important that construction vibration be minimised insofar as possible through best practice measures, the community be kept informed of construction works in advance, particularly tunnelling progress, and that any complaints are promptly addressed.

Vibration levels have been predicted for tunnelling operations between portals and have been assessed against the sleep disturbance guide level. In some areas above the Northern Link tunnels, the sleep disturbance guide level is predicted to be exceeded which indicates that sleep disturbance may result.

Anticipated vibration levels will be much lower than the calculated equivalent PPV where health risks may become an issue. Therefore, the health risk associated with generated vibration levels during construction may be considered extremely low.

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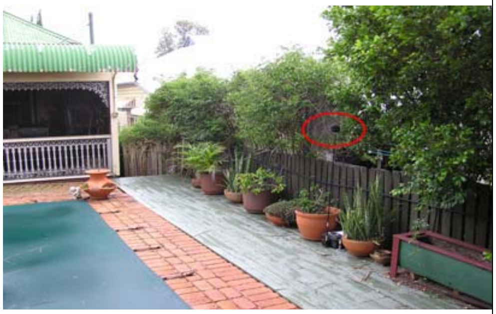
Monitoring Location	Description	Logger Location Image
1 - 22 Crag Road, Taringa	Front yard of detached single storey dwelling at 22 Crag Street, Taringa, facing Western Freeway	
2 - 115 Elizabeth Street, Toowong	High side of front yard of detached highset dwelling at 115 Elizabeth Street, Toowong	
3 - 6 Wool Street, Toowong	Front yard of single-storey detached dwelling at 6 Wool Street, Toowong	
4 - 128 Sylvan Road, Toowong	Front yard of block of units at 128 Sylvan Road, Toowong	

5 - 29 Valentine Street, Toowong	Front yard (facing towards Milton Road) of detached highset dwelling at 29 Valentine Street, Toowong	
6 - 69 Frederick Street, Toowong	Front verandah of highset detached dwelling at 69 Frederick Street, Toowong	
7 - 9 Victoria Crescent, Toowong	Front yard of detached double-storey dwelling at 9 Victoria Crescent, Toowong	
8 - 5 Clyde Street, Brisbane City	Front patio of detached single-storey dwelling at 5 Clyde Street, Brisbane City	
9 - 26 Lower Clifton Terrace, Red Hill	Front yard of detached double-storey dwelling at 26 Lower Clifton Terrace, Red Hill	

10 – 7 Westbury Street, Red Hill	Front yard of detached single-storey dwelling at 7 Westbury Street, Red Hill	
11– Inner Northern Busway (INB), Normanby Station	Located on parcel of Translink land between Ithaca St and INB east of Normanby Busway Station	
12 – 43 Normanby Terrace, Kelvin Grove	Rear yard (overlooking ICB) of detached highset dwelling at 43 Normanby Terrace, Kelvin Grove	
13 – 9 Horrocks Street, Toowong	Low side yard of highset dwelling	
14 – QUT Kelvin Grove Campus	Adjacent to south end of block Y1	

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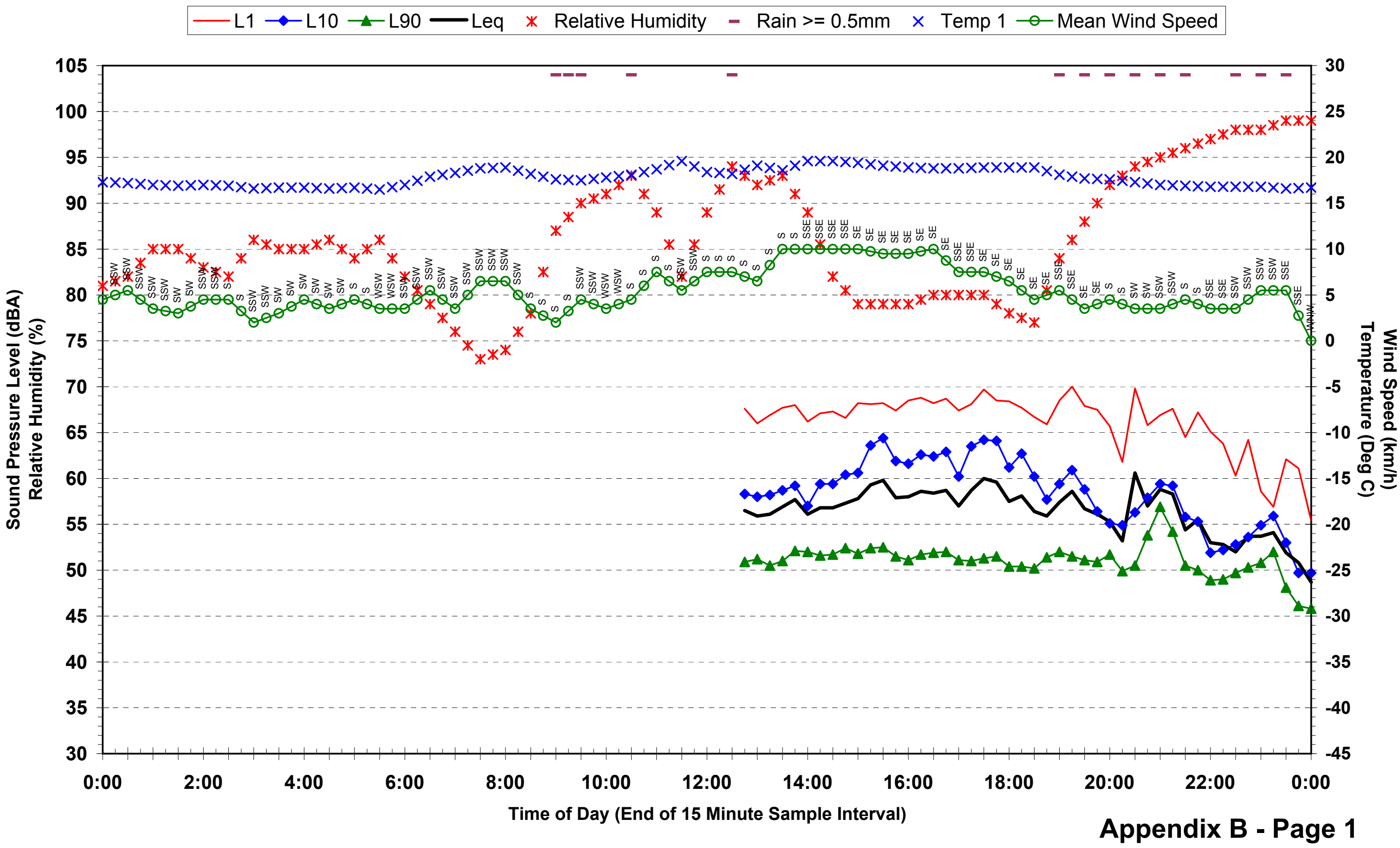
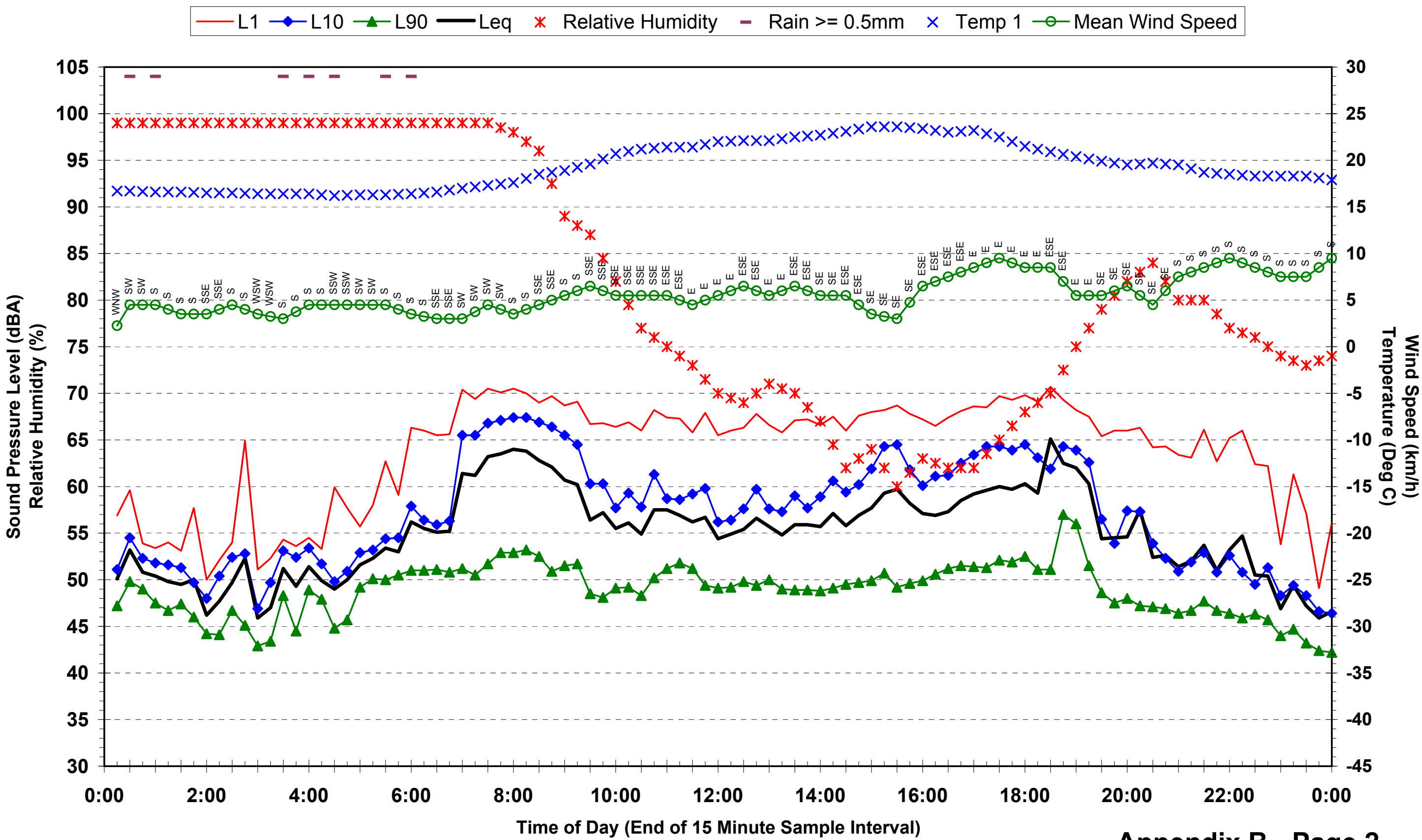
Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Wednesday 7 November 2007

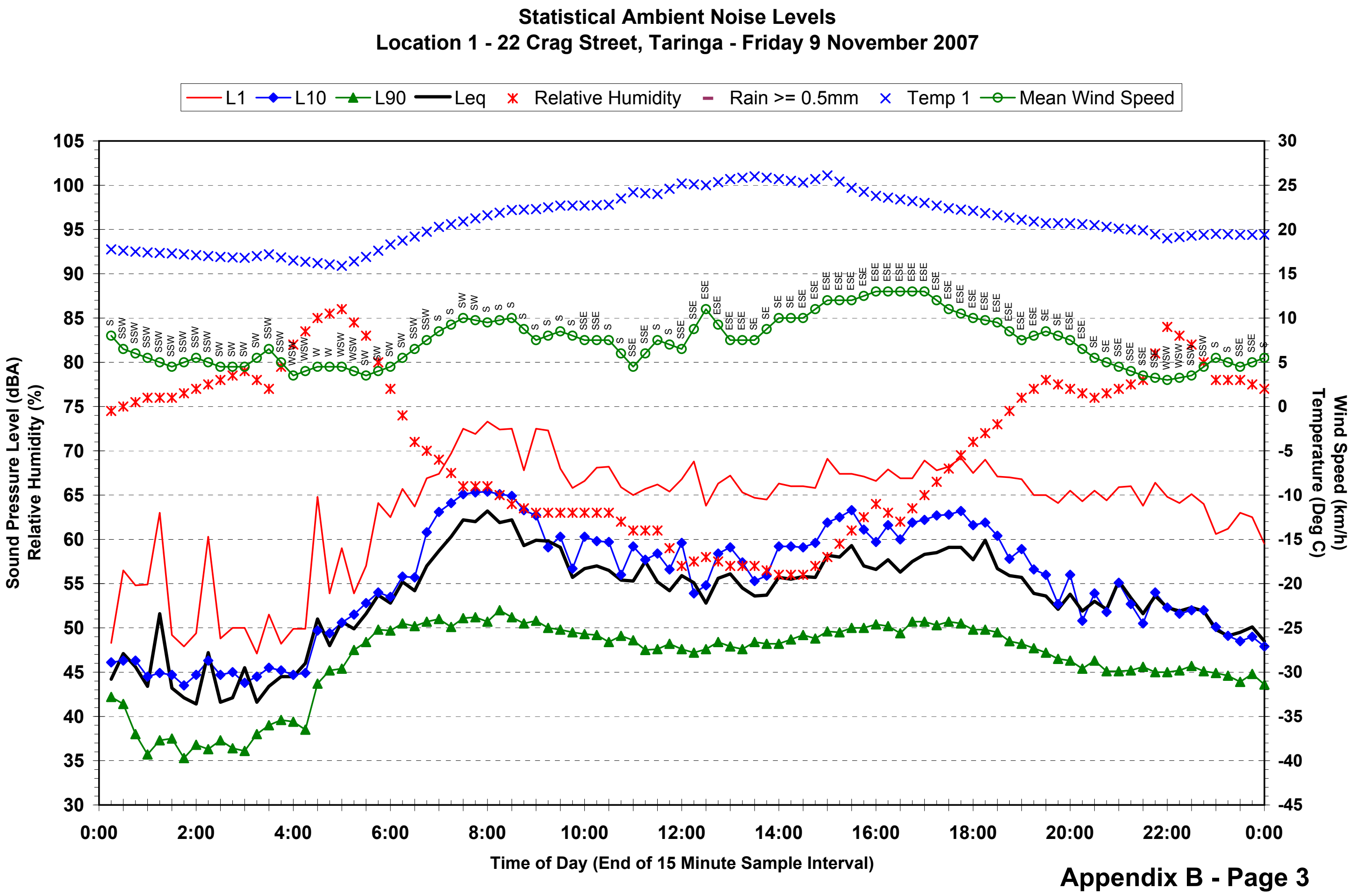


Appendix B - Page 1
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Thursday 8 November 2007



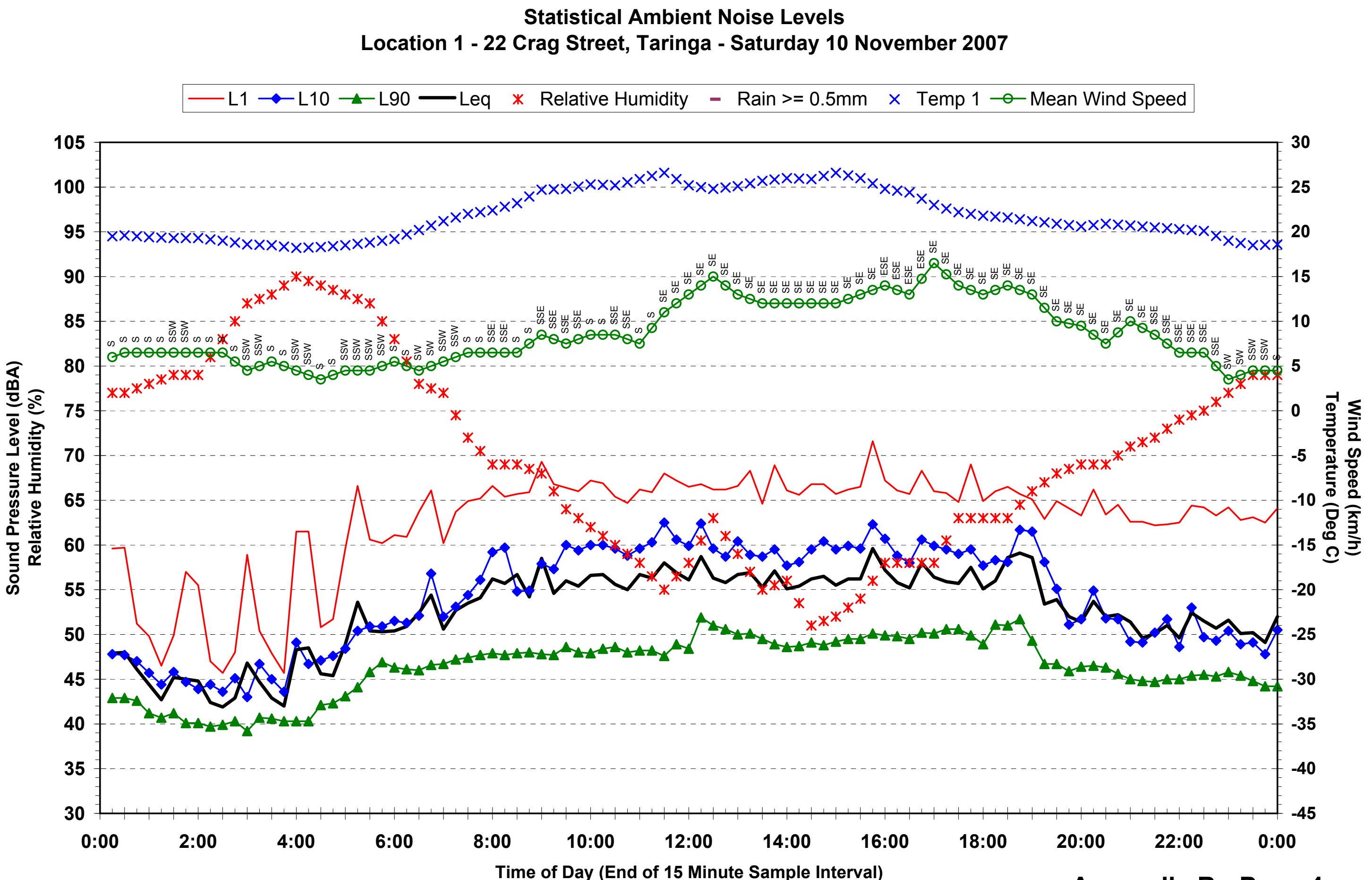
Appendix B - Page 2
Ambient Conditions
Heggies Report 20-1854



Appendix B - Page 3

Ambient Conditions

Heggies Report 20-1854

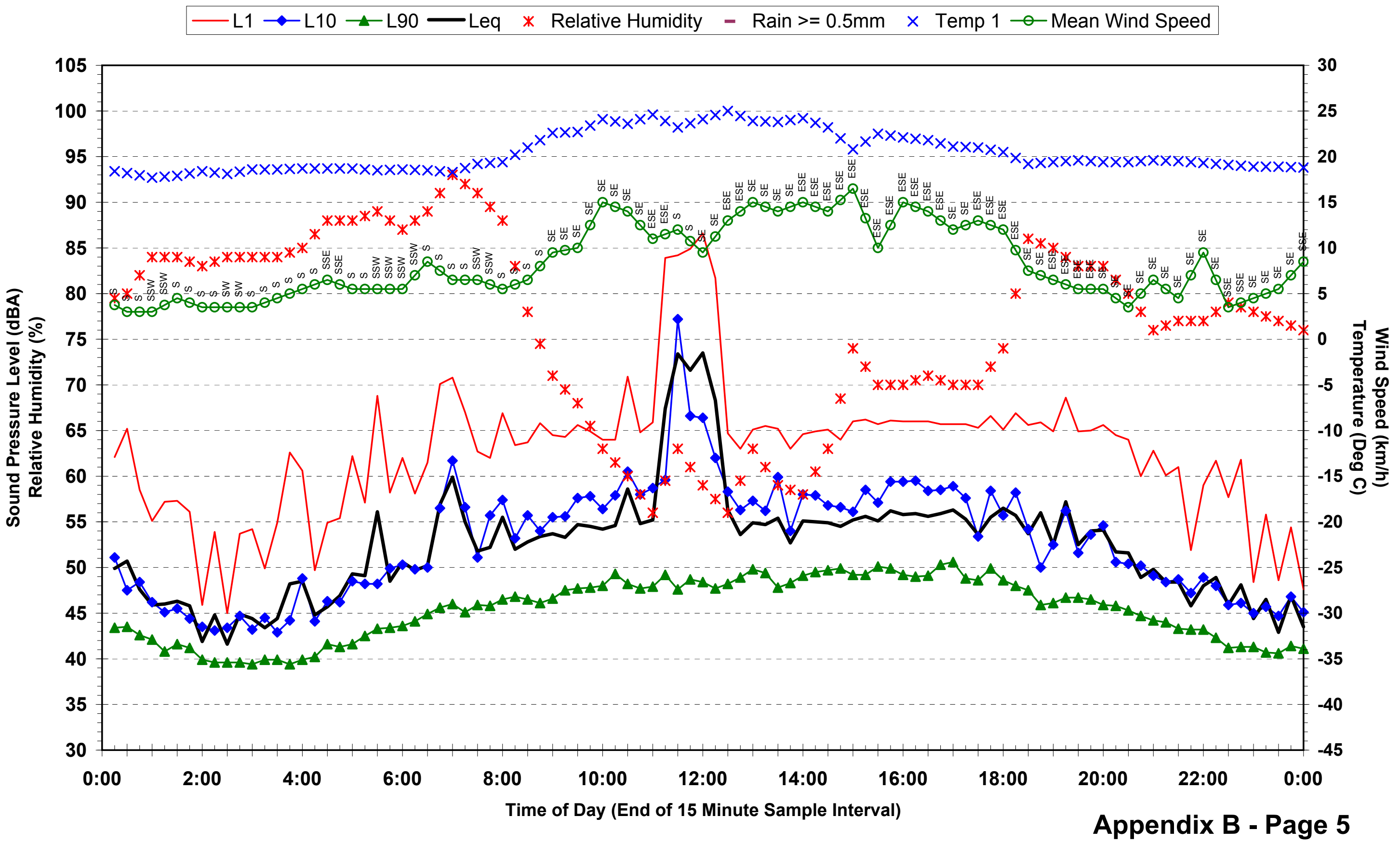


Appendix B - Page 4

Ambient Conditions

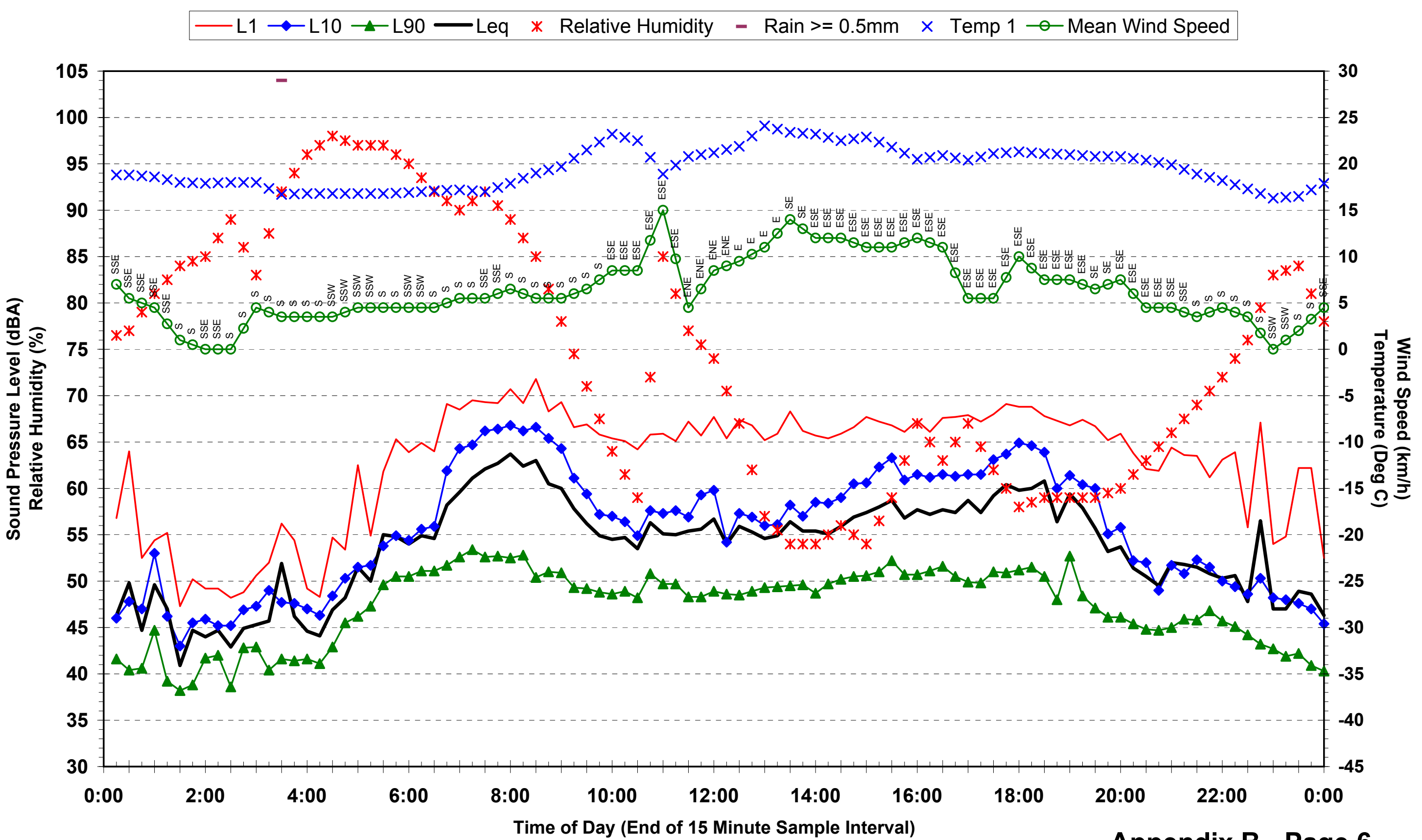
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Sunday 11 November 2007



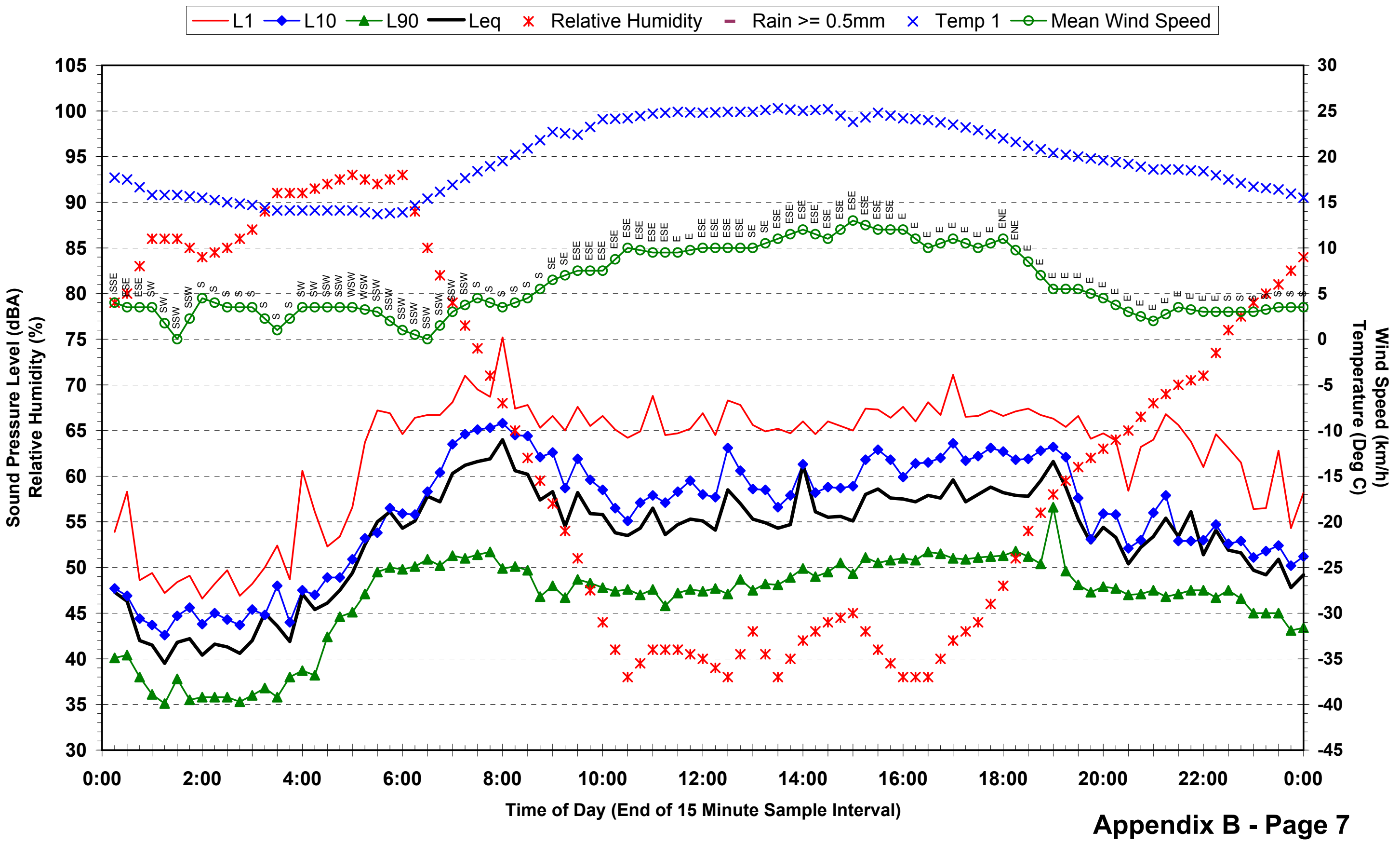
Appendix B - Page 5
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Monday 12 November 2007



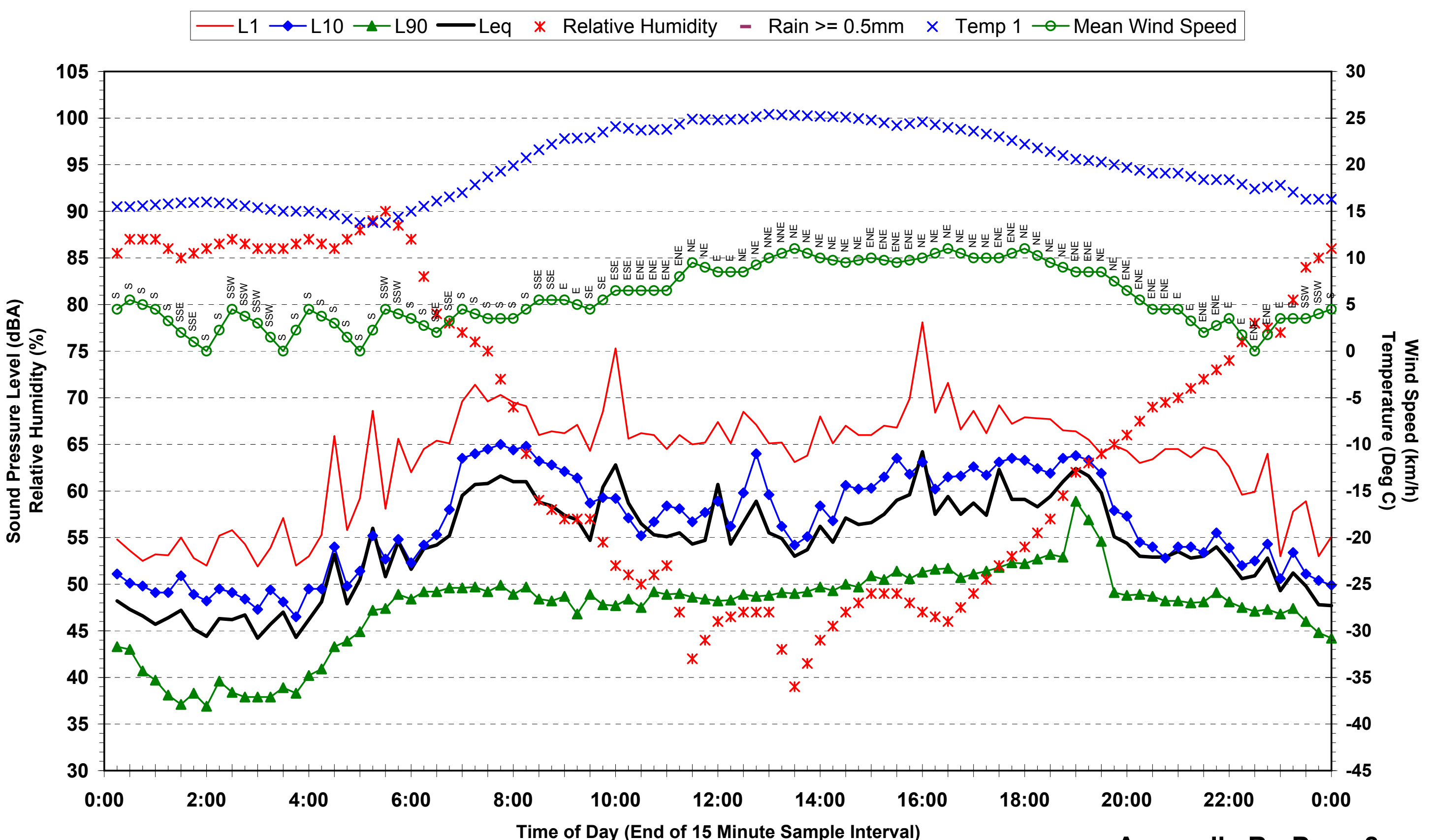
Appendix B - Page 6
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Tuesday 13 November 2007



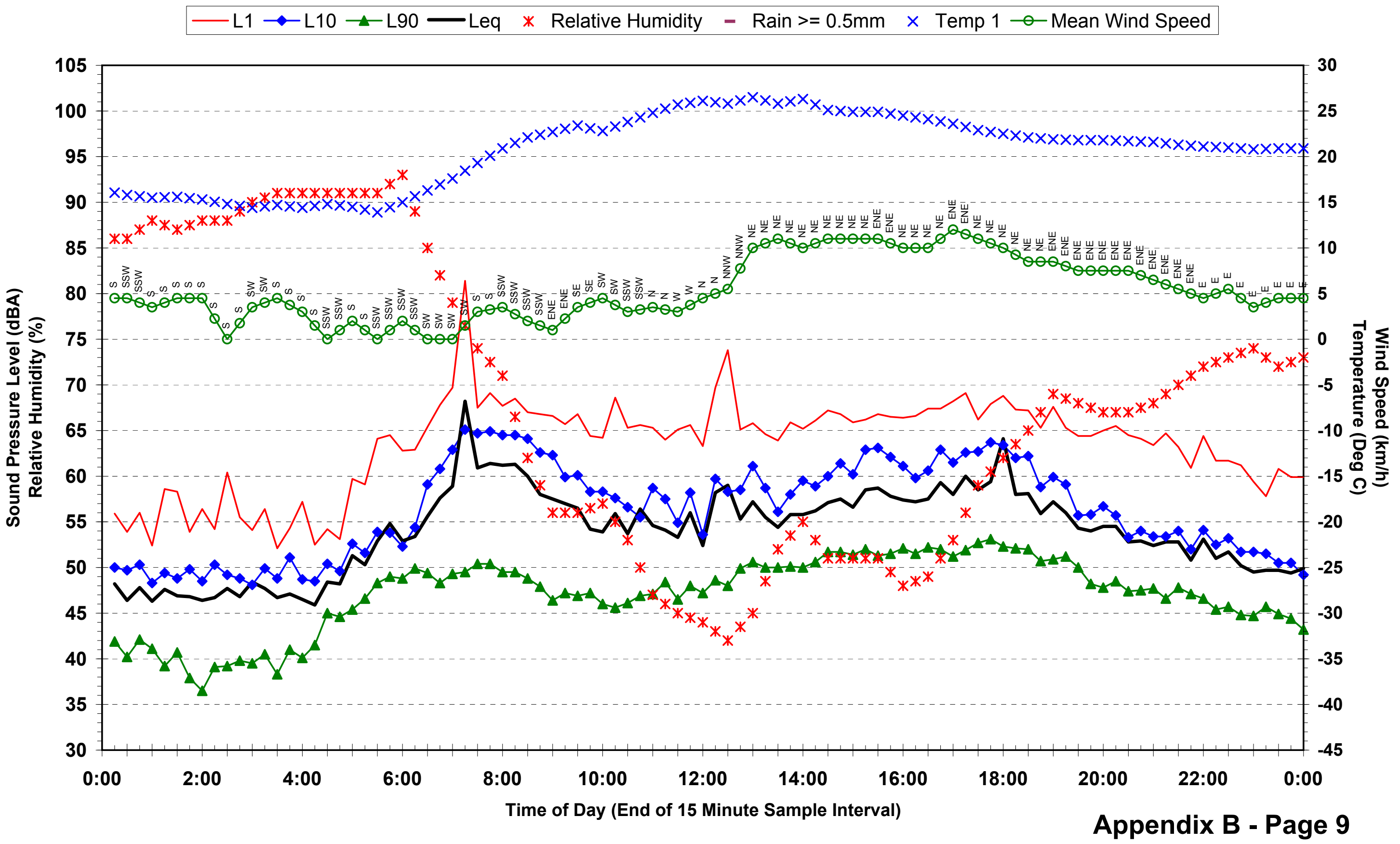
Appendix B - Page 7
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Wednesday 14 November 2007



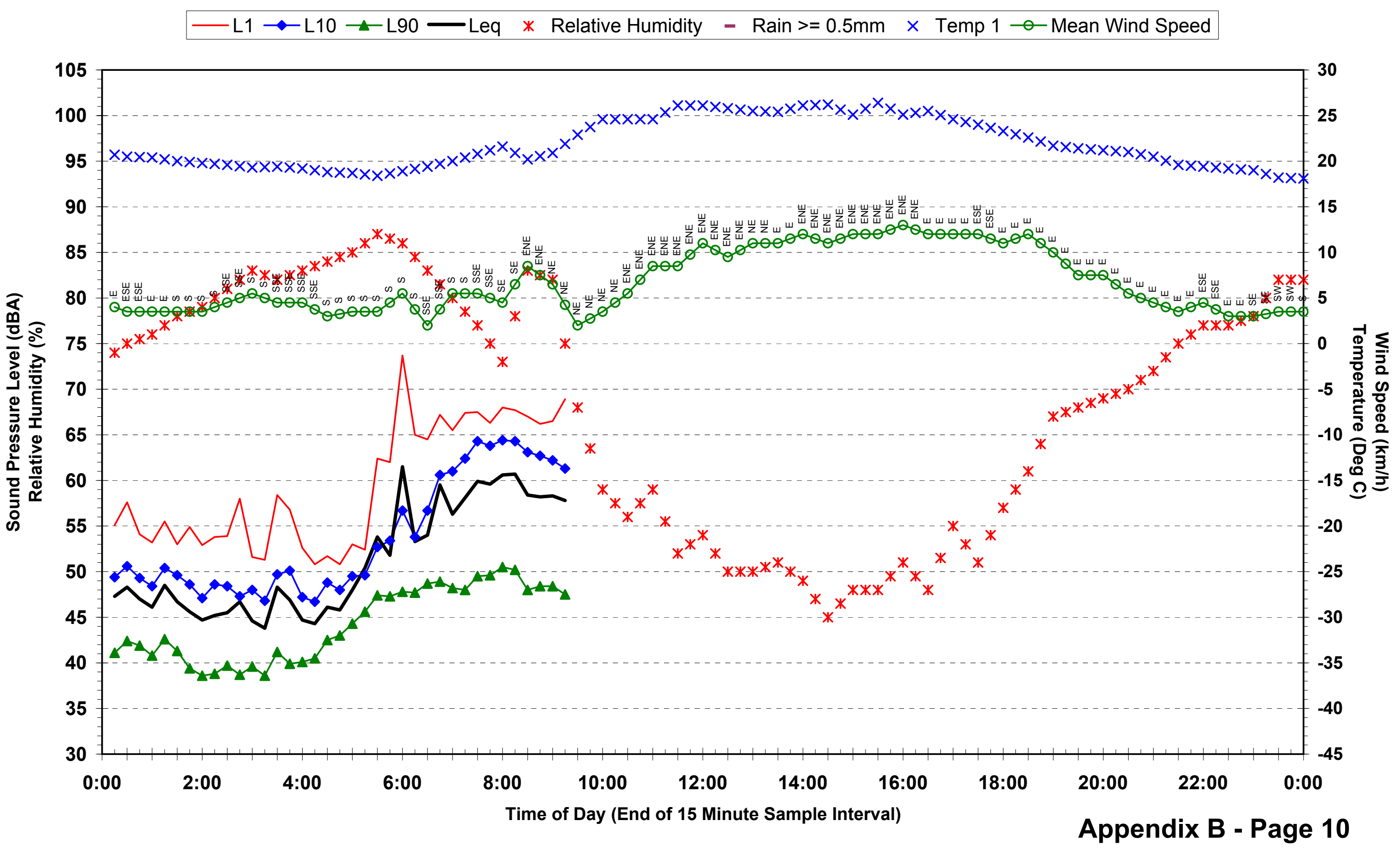
Appendix B - Page 8
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Thursday 15 November 2007



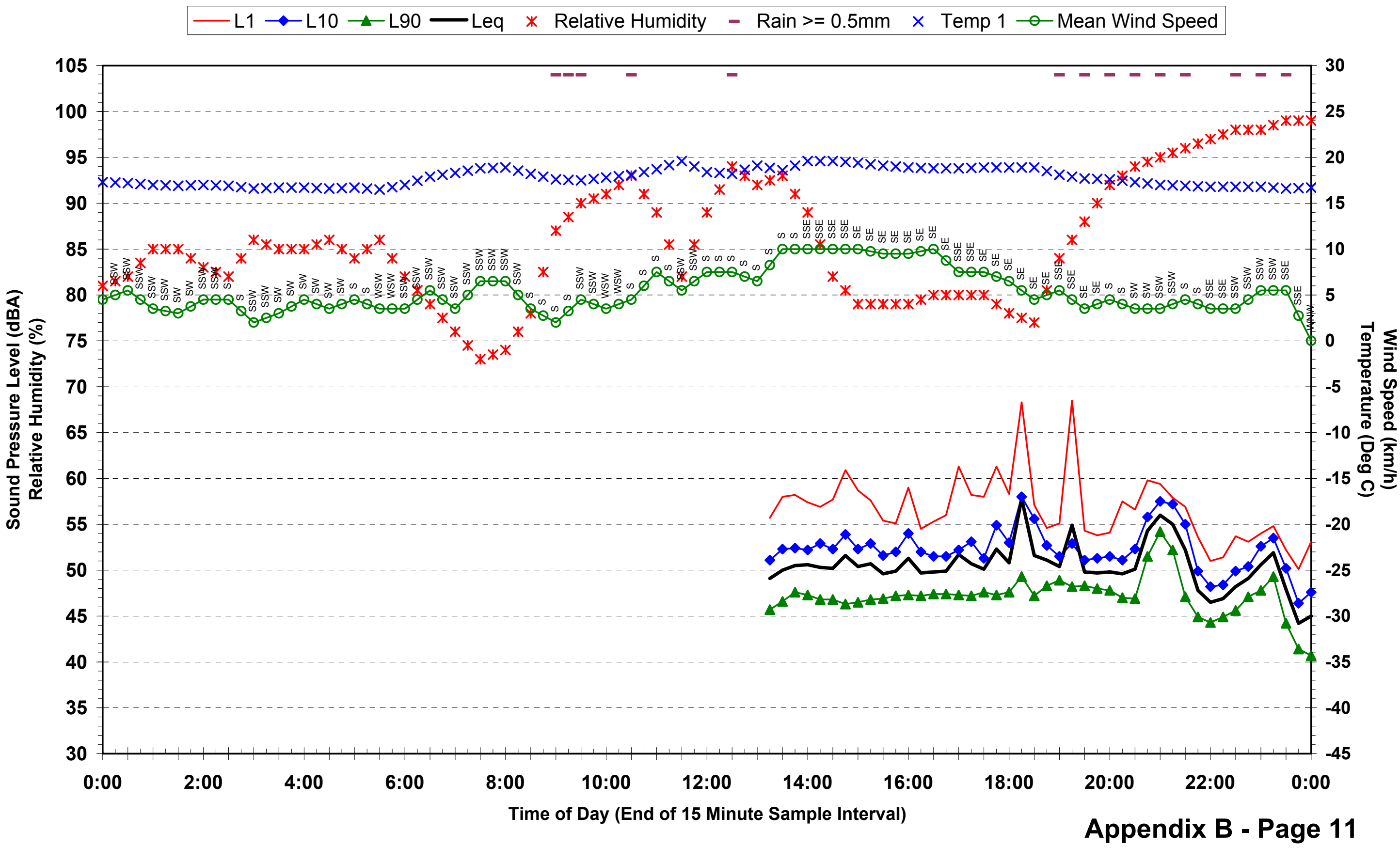
Appendix B - Page 9
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 1 - 22 Crag Street, Taringa - Friday 16 November 2007



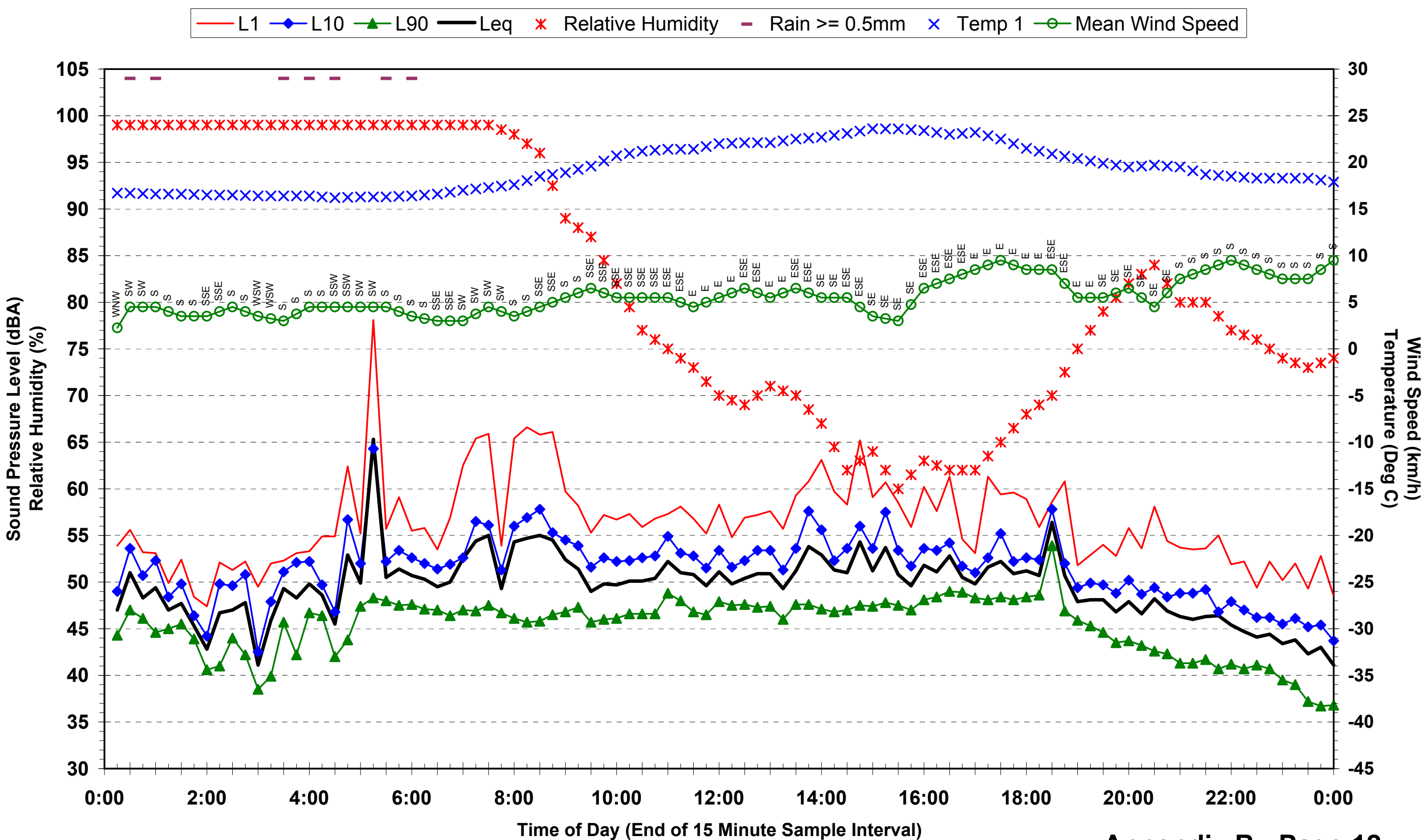
Appendix B - Page 10
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Wednesday 7 November 2007



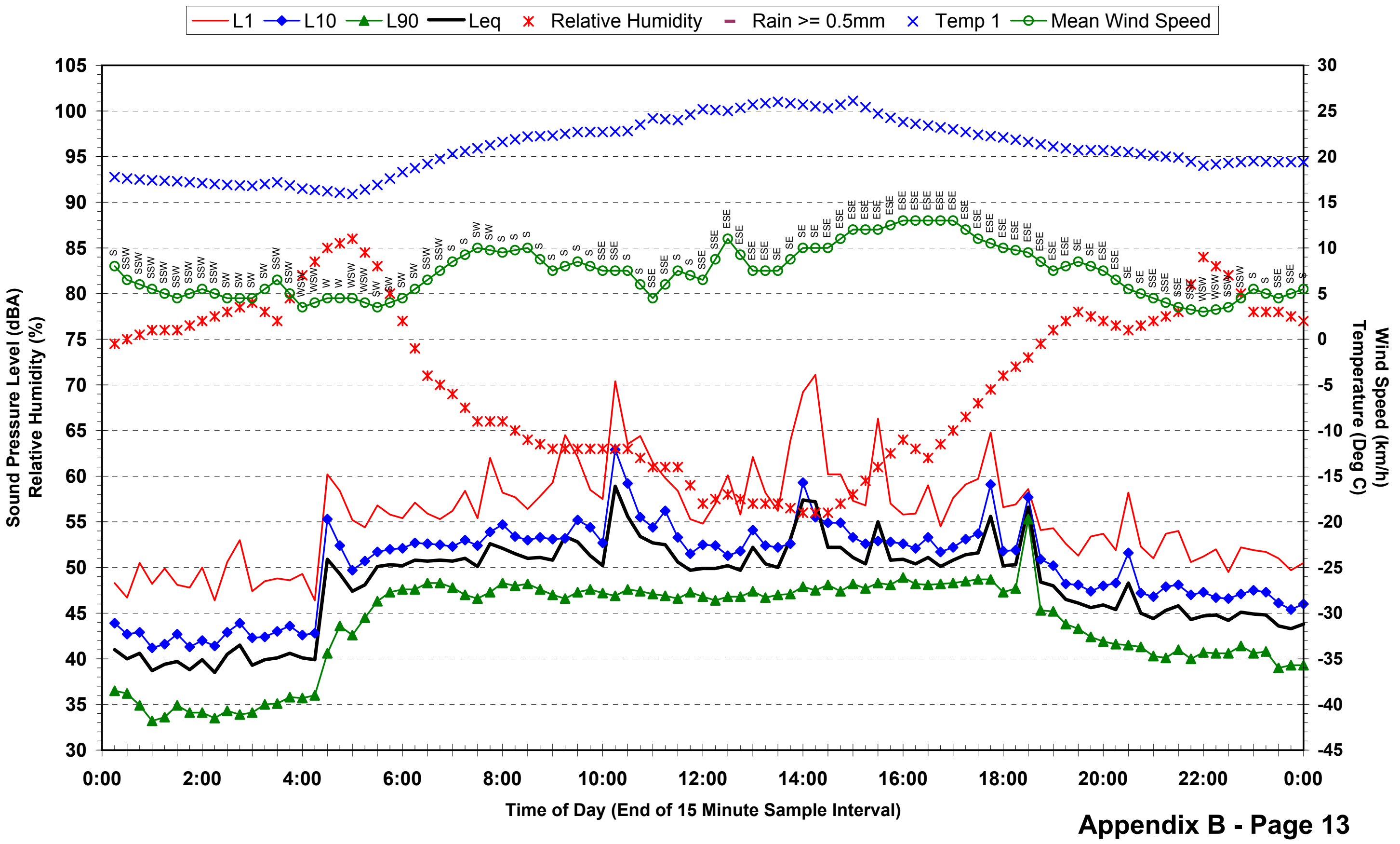
Appendix B - Page 11
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Thursday 8 November 2007



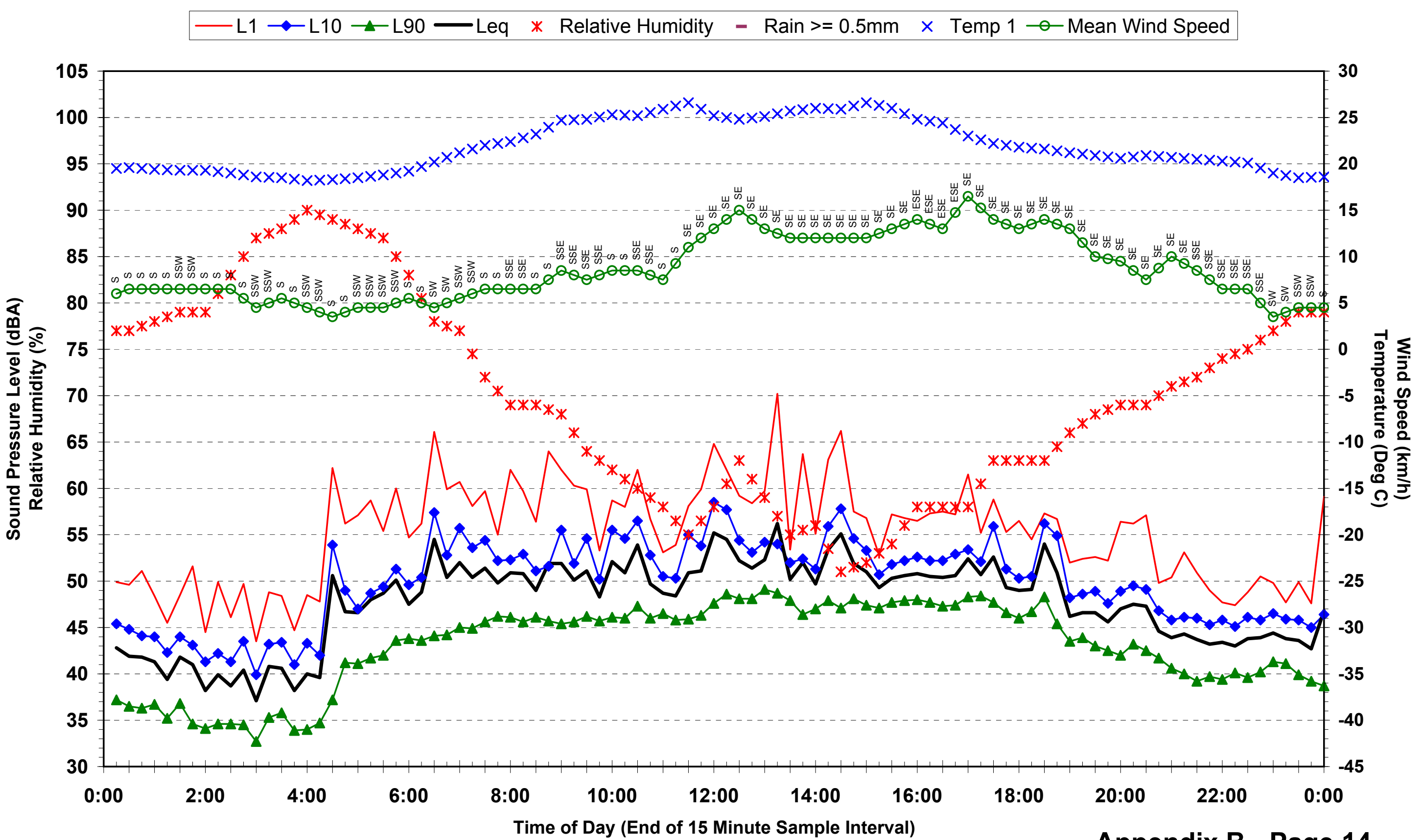
Appendix B - Page 12
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Friday 9 November 2007



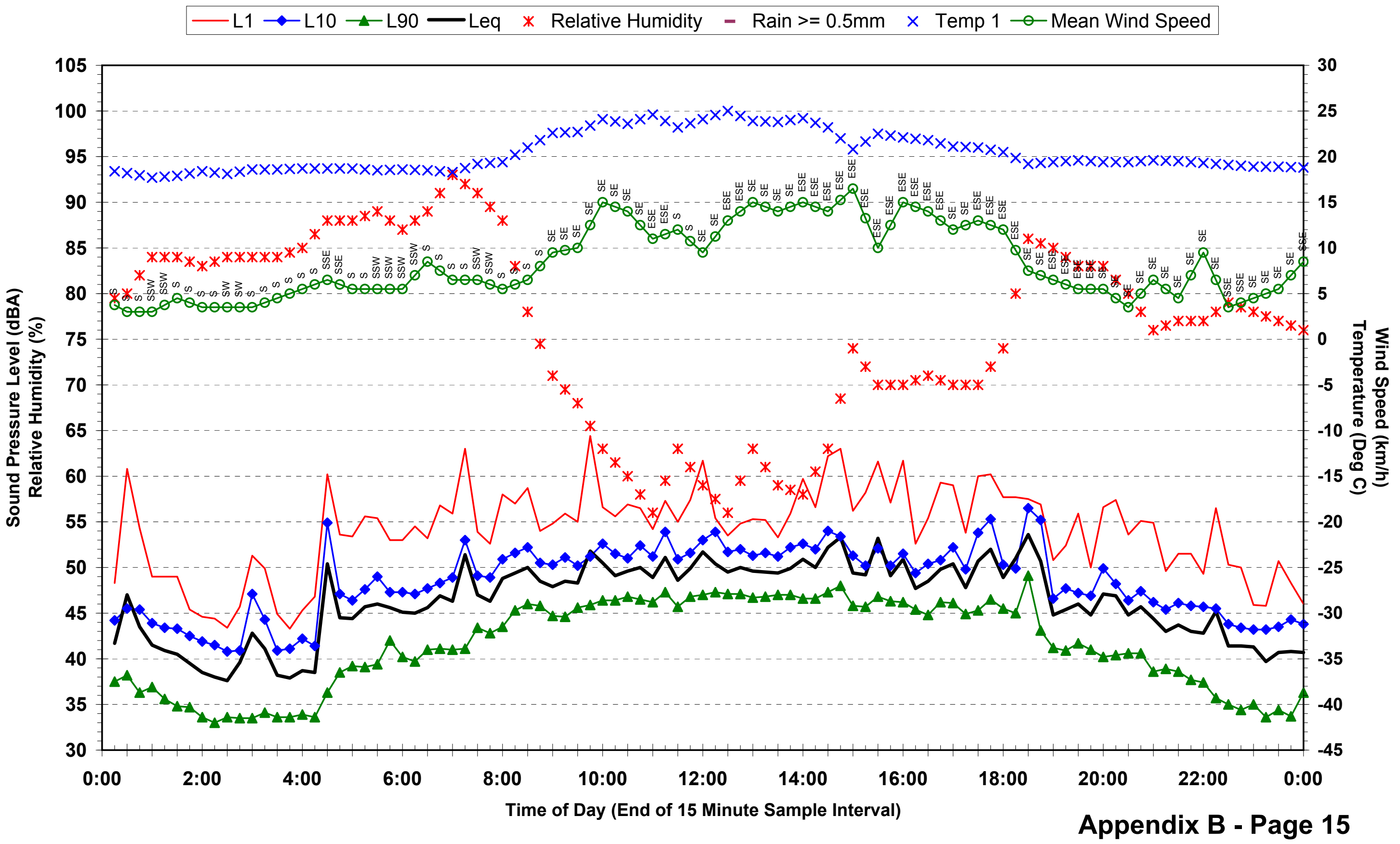
Appendix B - Page 13
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Saturday 10 November 2007



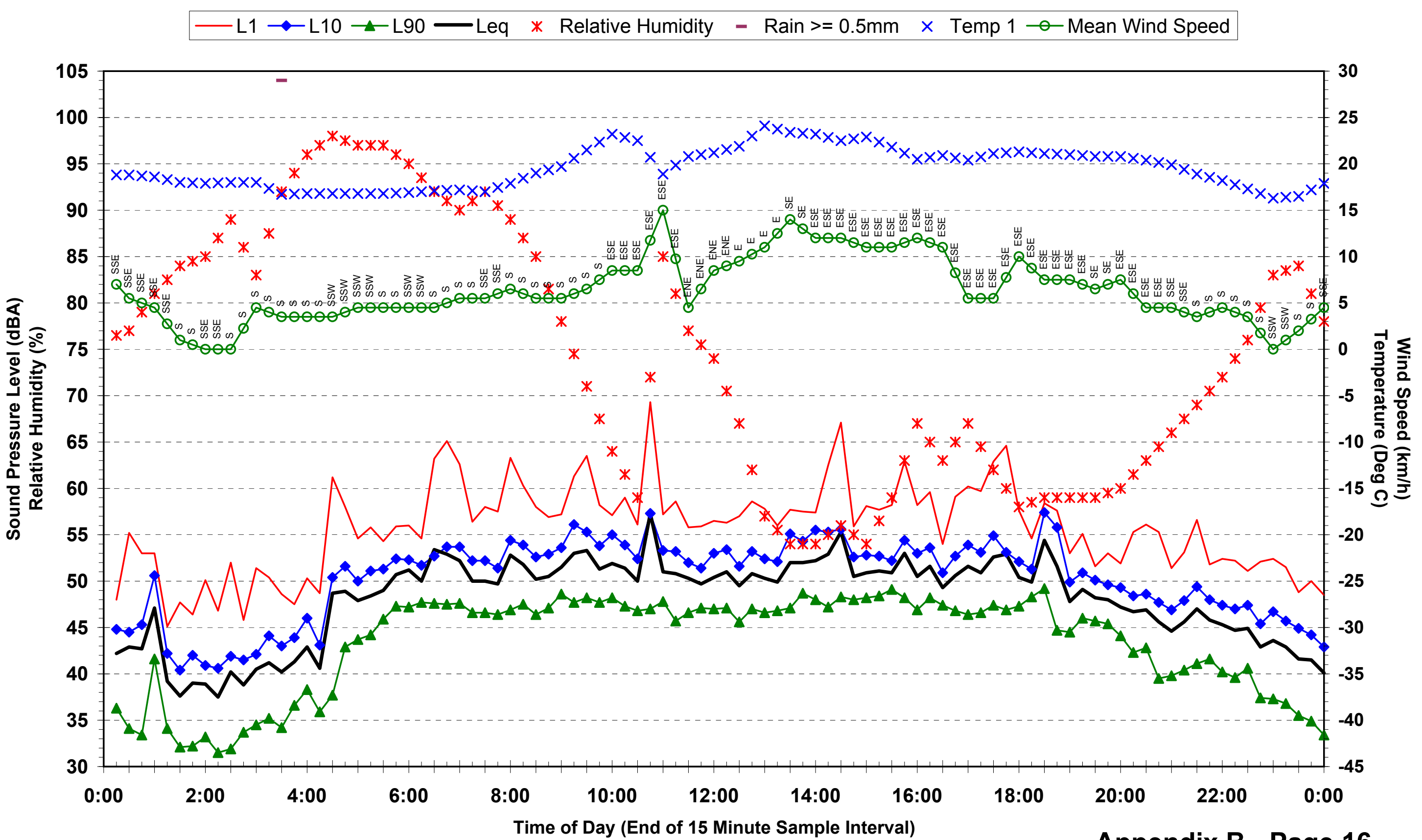
Appendix B - Page 14
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Sunday 11 November 2007



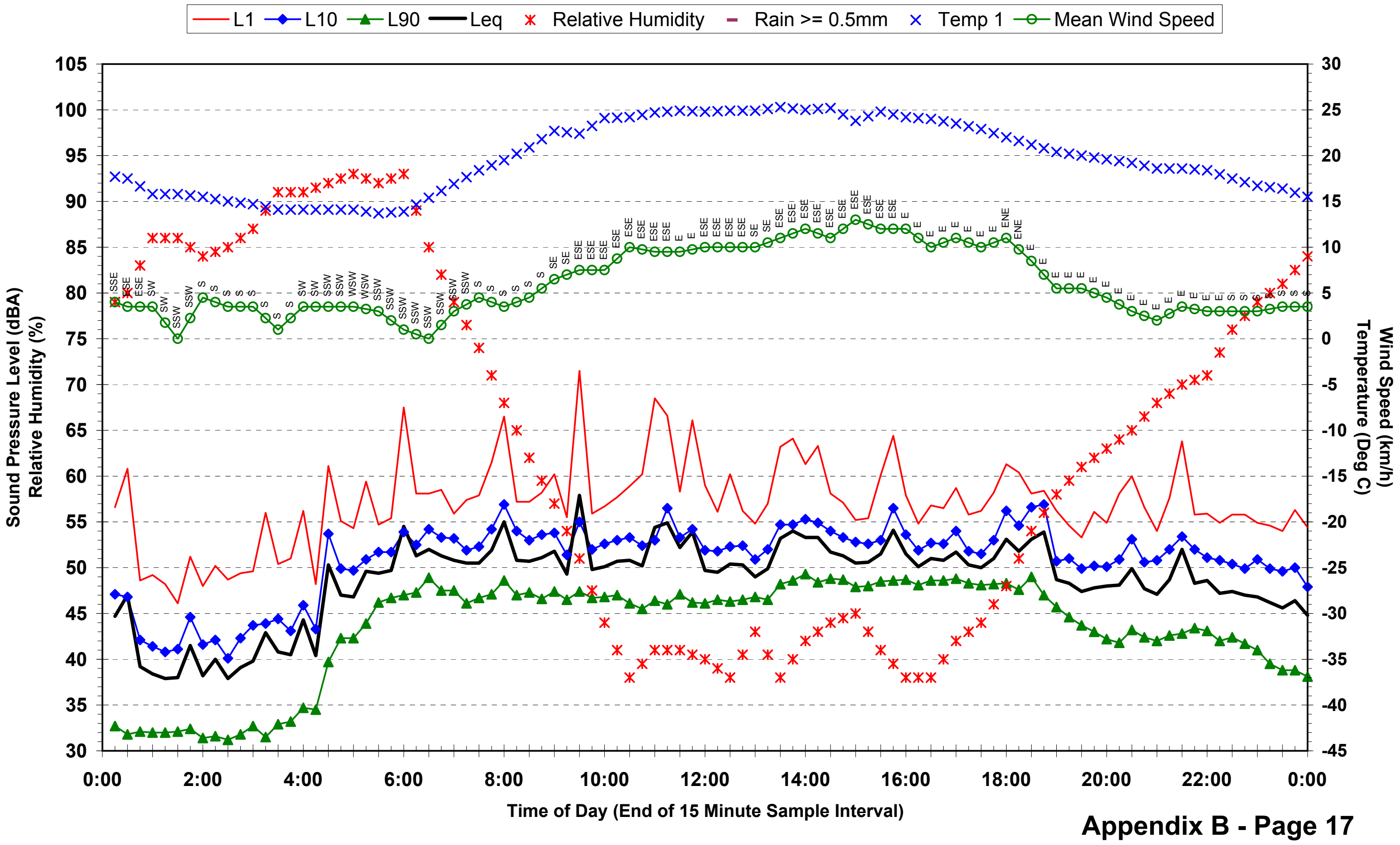
Appendix B - Page 15
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Monday 12 November 2007



Appendix B - Page 16
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Tuesday 13 November 2007

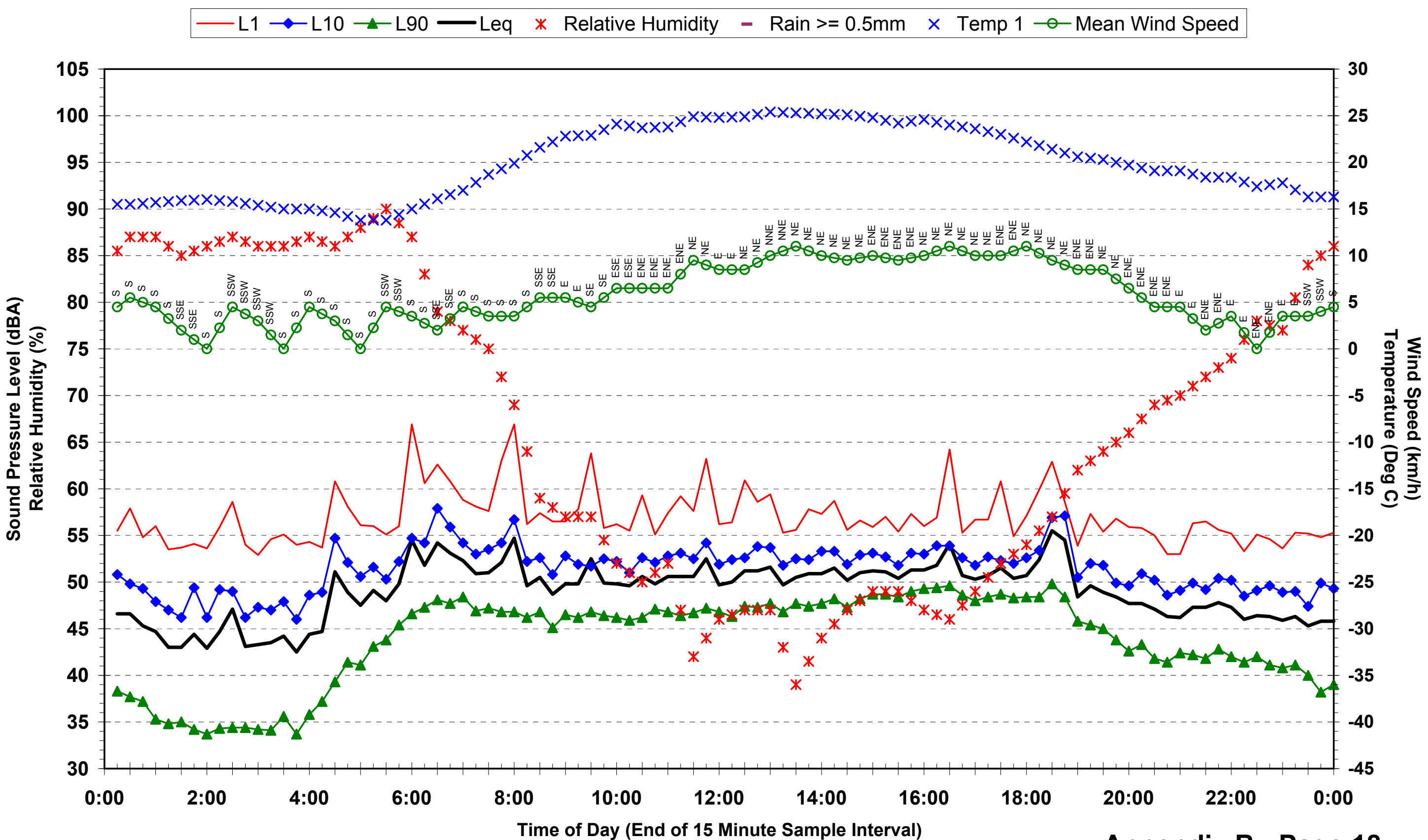


Appendix B - Page 17

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Wednesday 14 November 2007

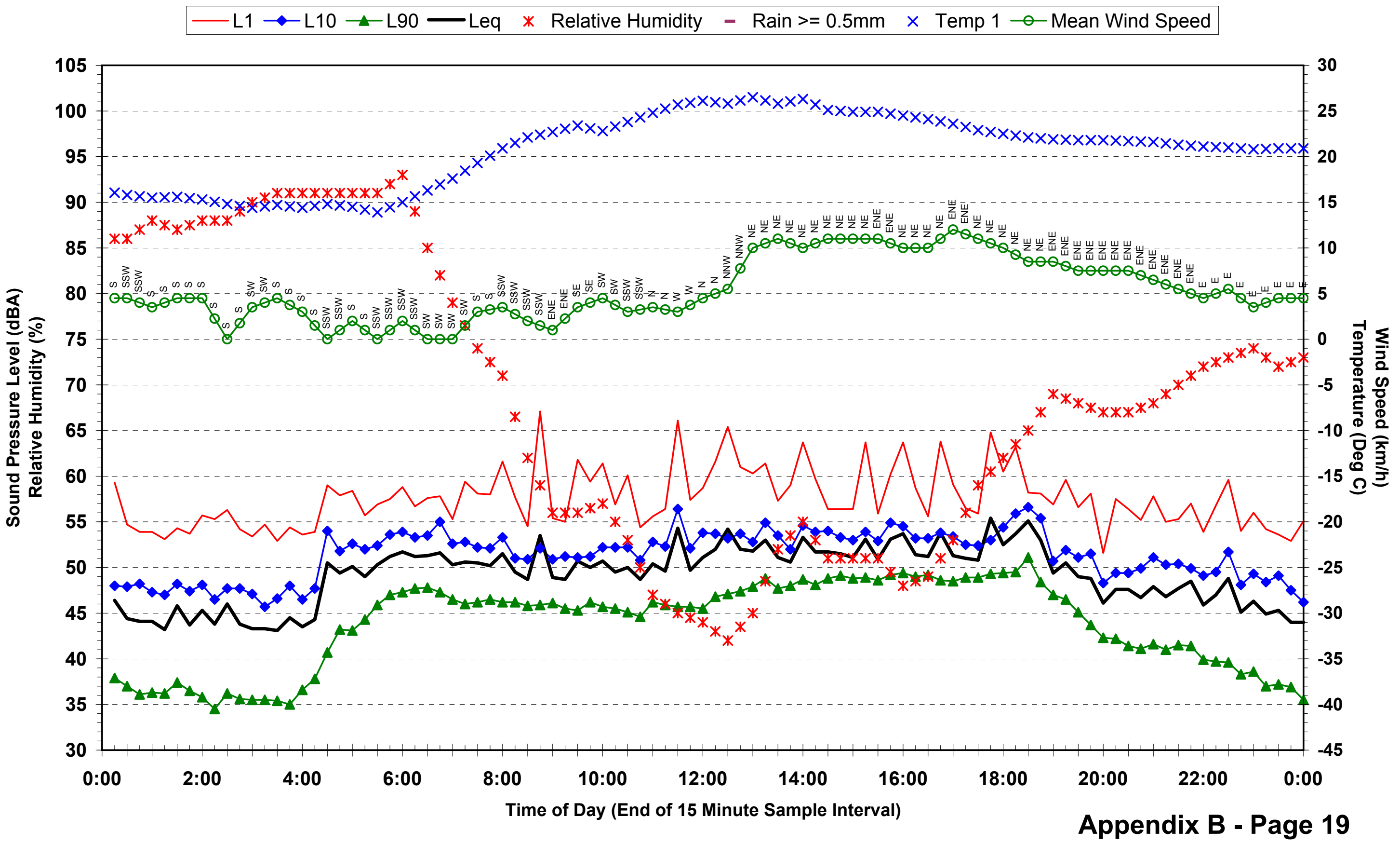


Appendix B - Page 18

Ambient Conditions

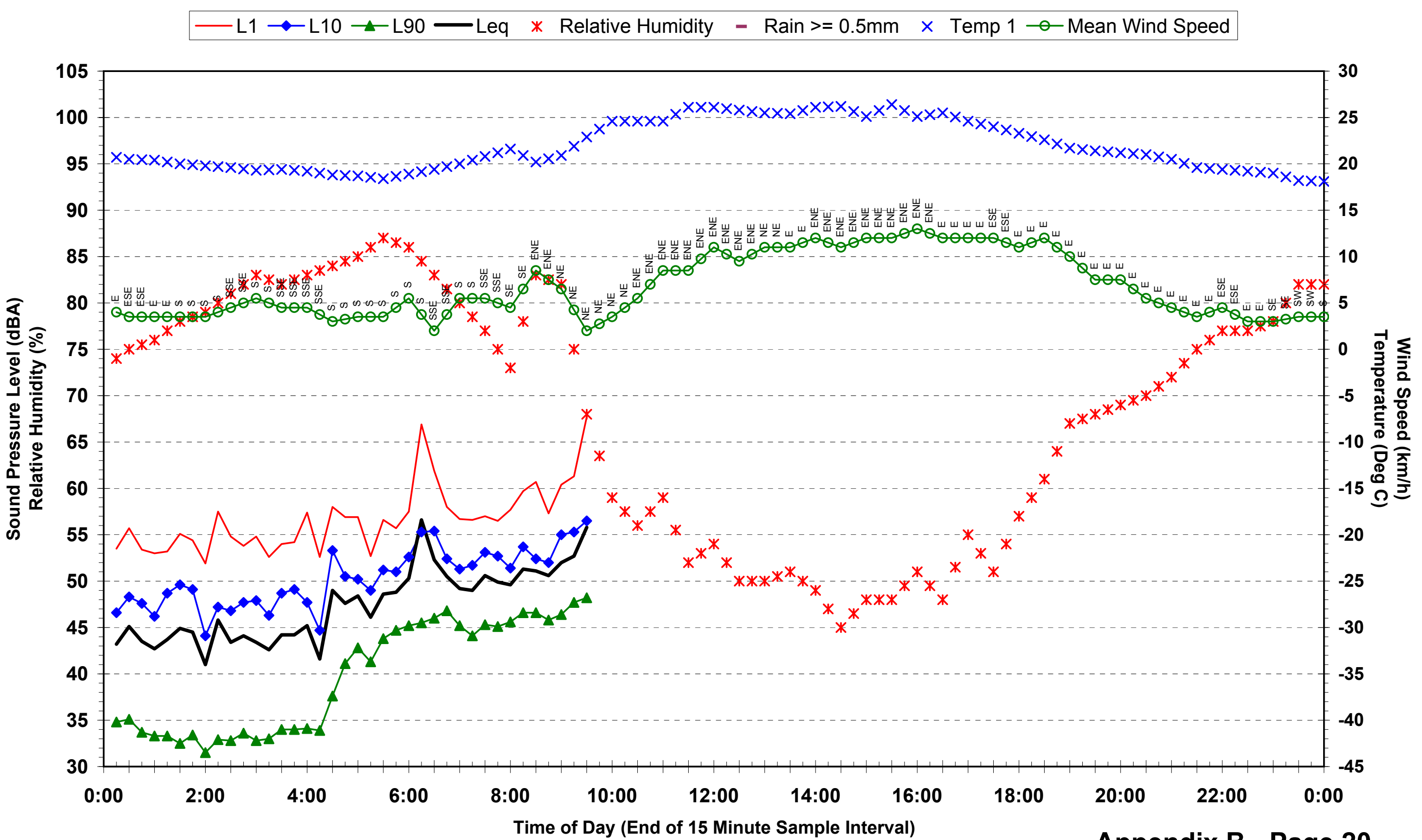
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Thursday 15 November 2007



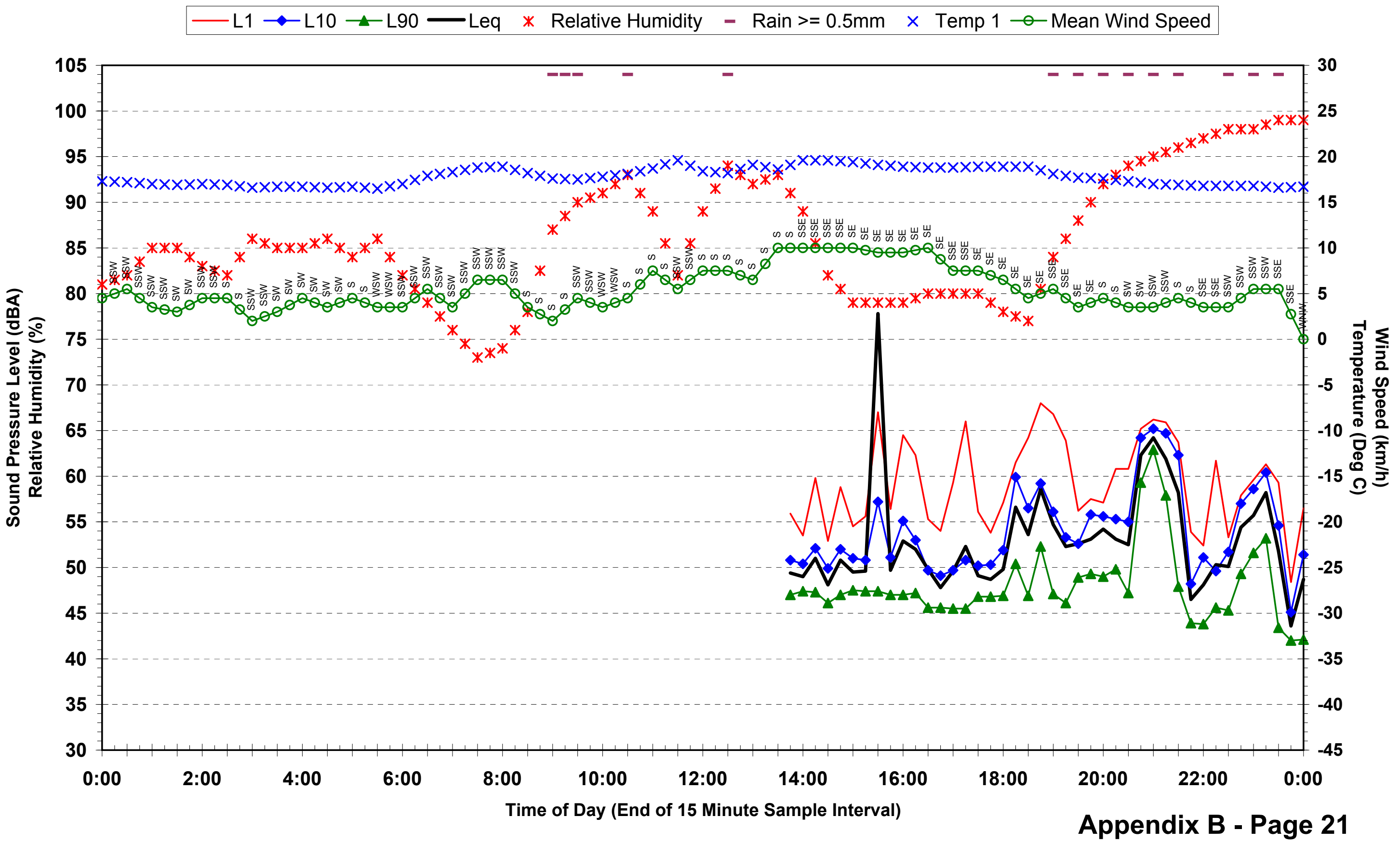
Appendix B - Page 19
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 2 - 115 Elizabeth Street, Toowong - Friday 16 November 2007



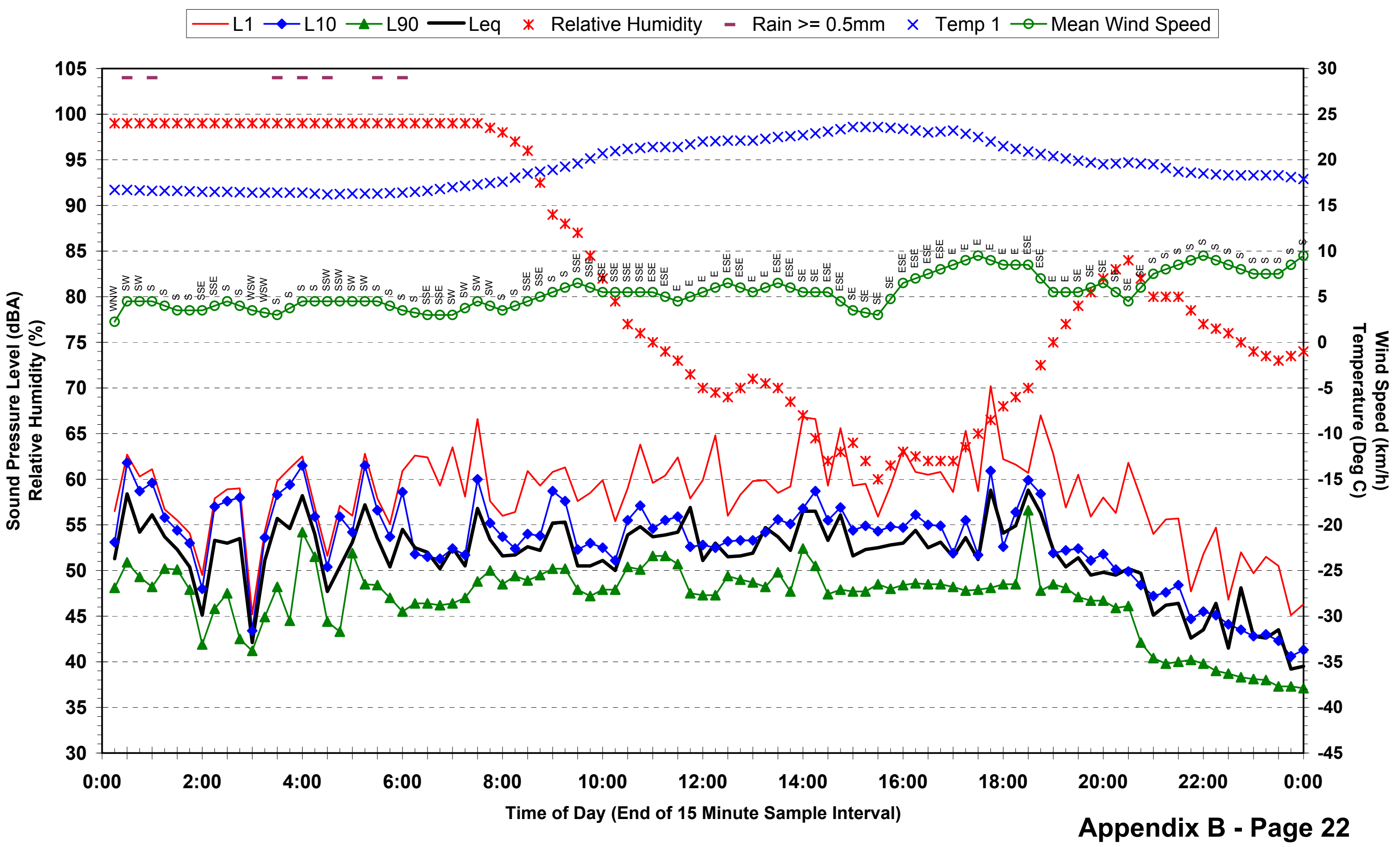
Appendix B - Page 20
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Wednesday 7 November 2007



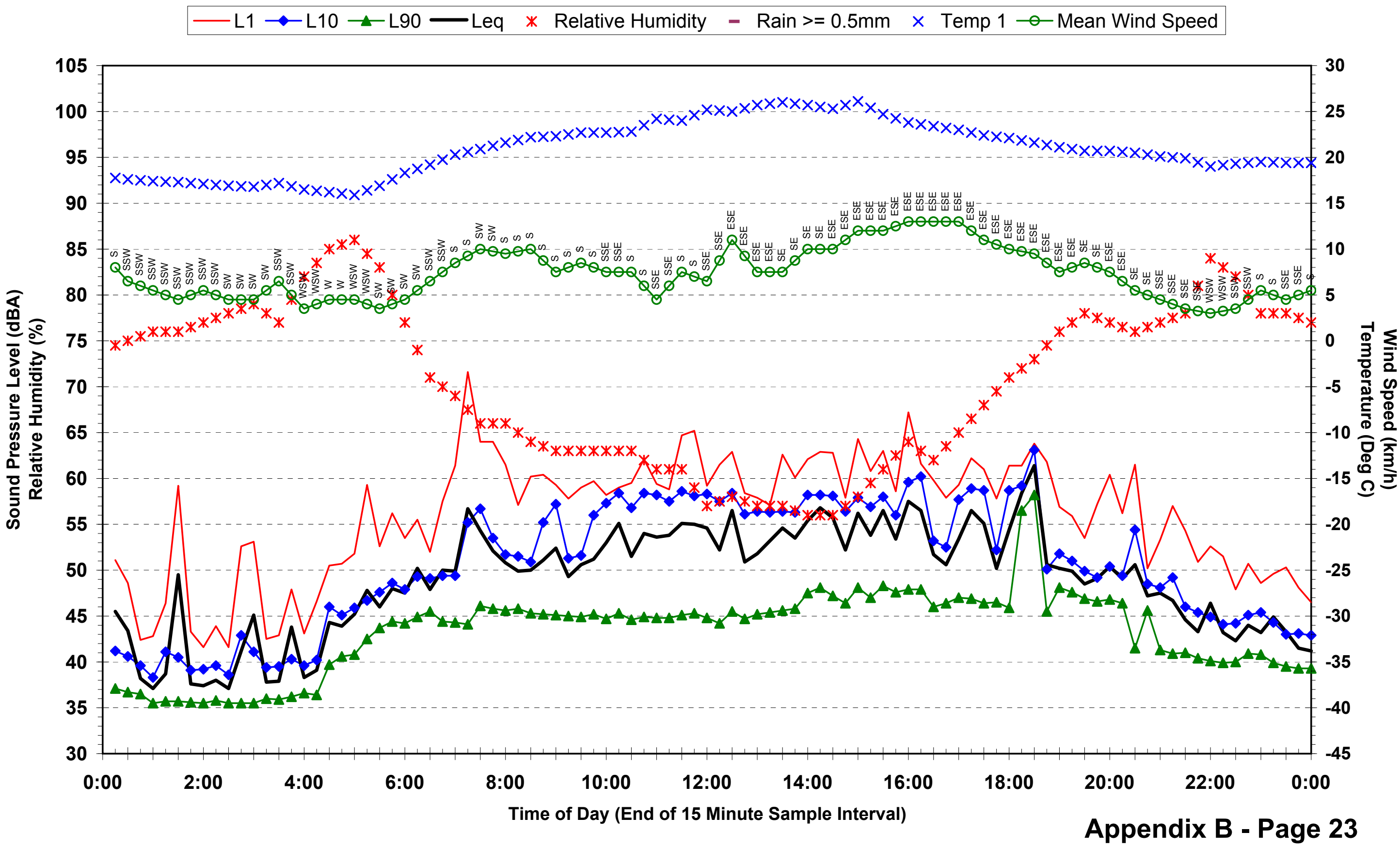
Appendix B - Page 21
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Thursday 8 November 2007



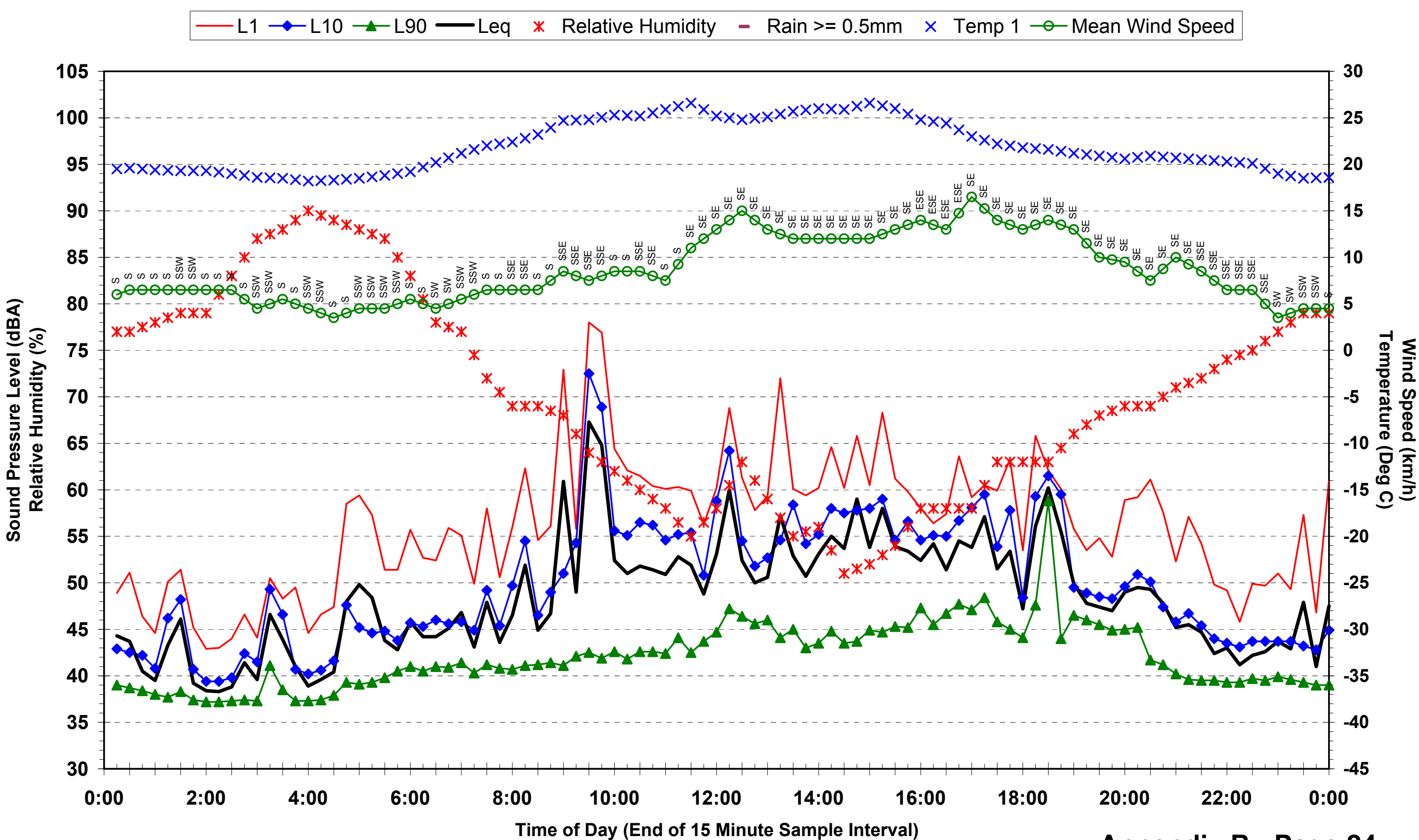
Appendix B - Page 22
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Friday 9 November 2007



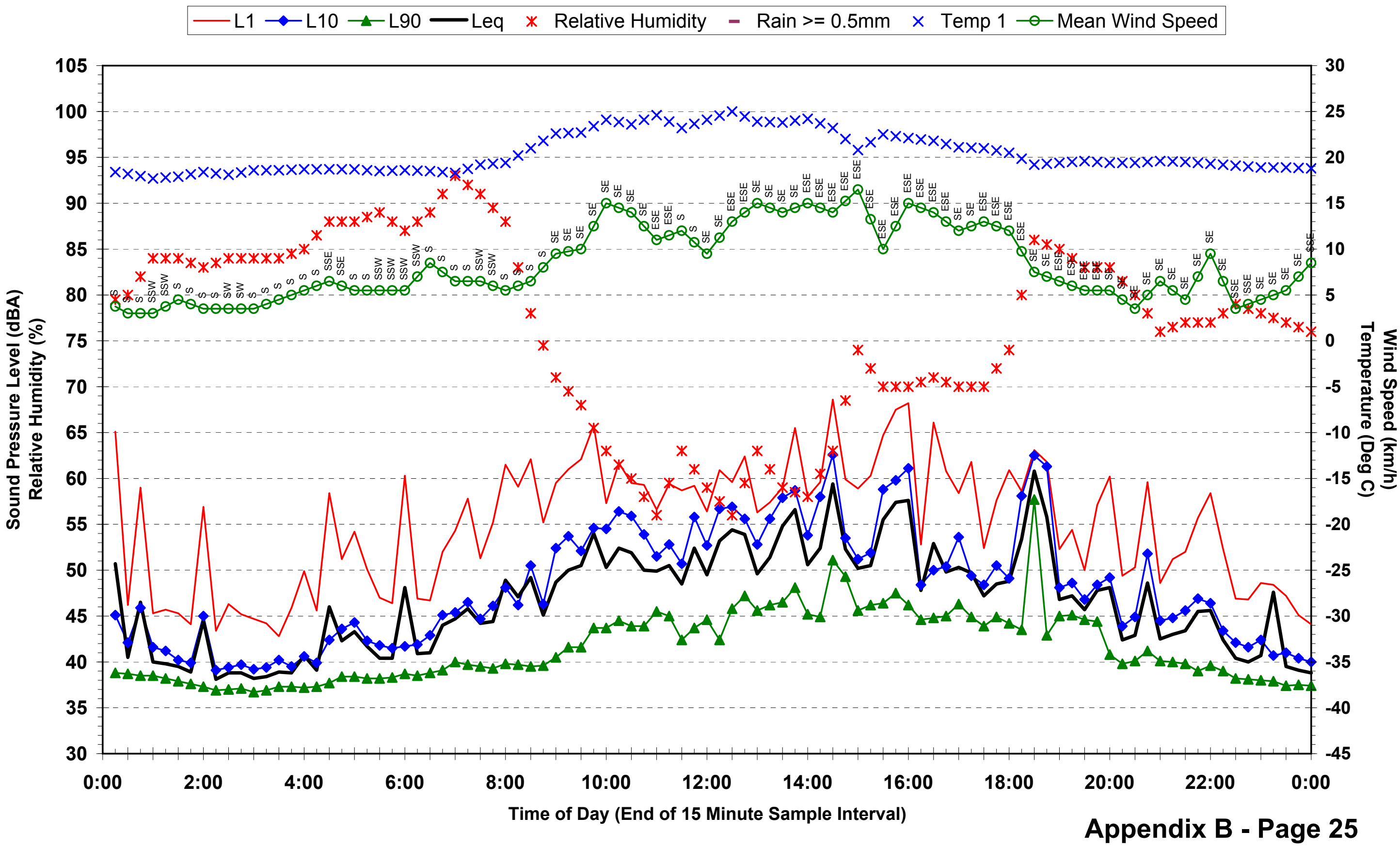
Appendix B - Page 23
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Saturday 10 November 2007



Appendix B - Page 24
Ambient Conditions
Heggies Report 20-1854

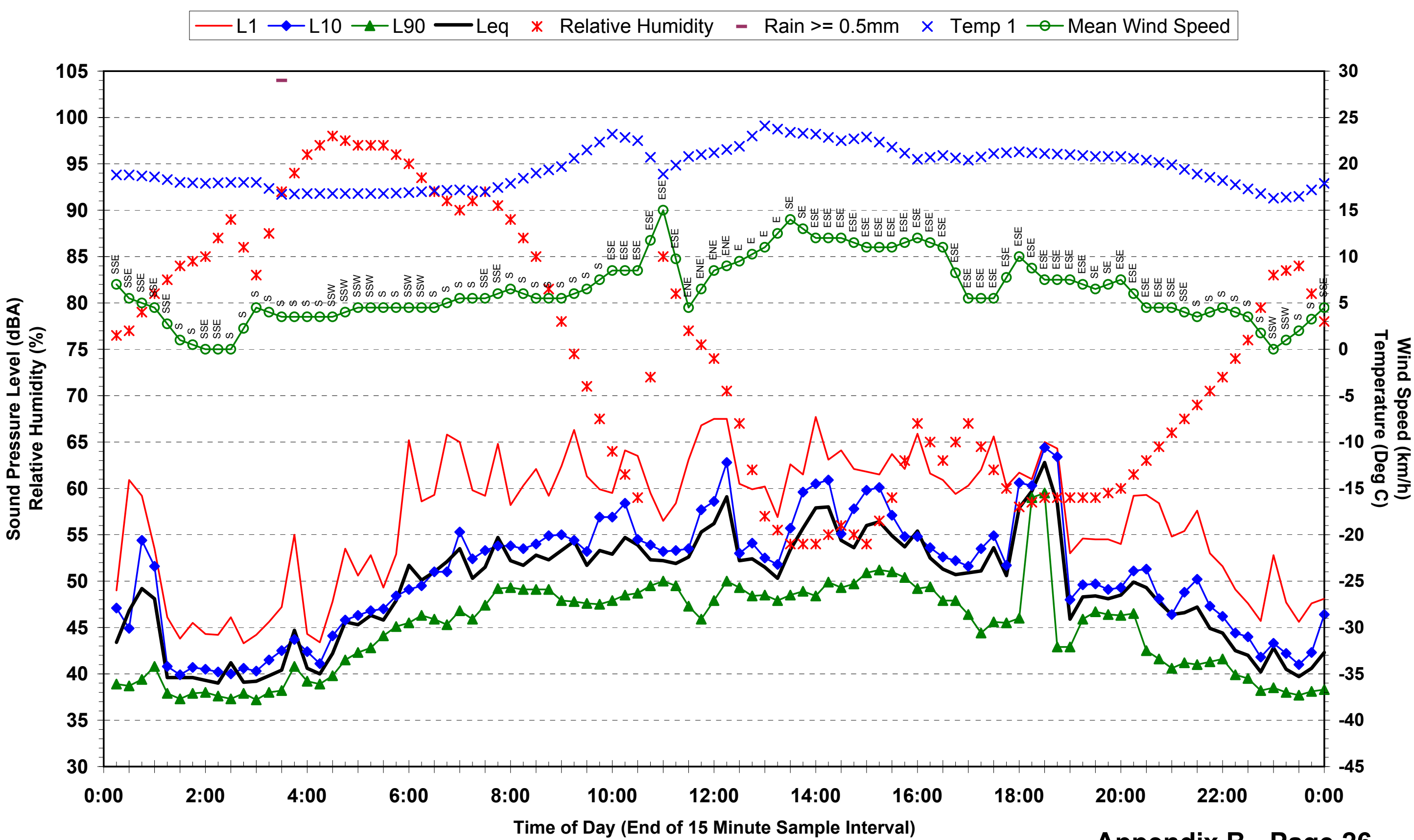
Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Sunday 11 November 2007



Appendix B - Page 25

Ambient Conditions
Heggies Report 20-1854

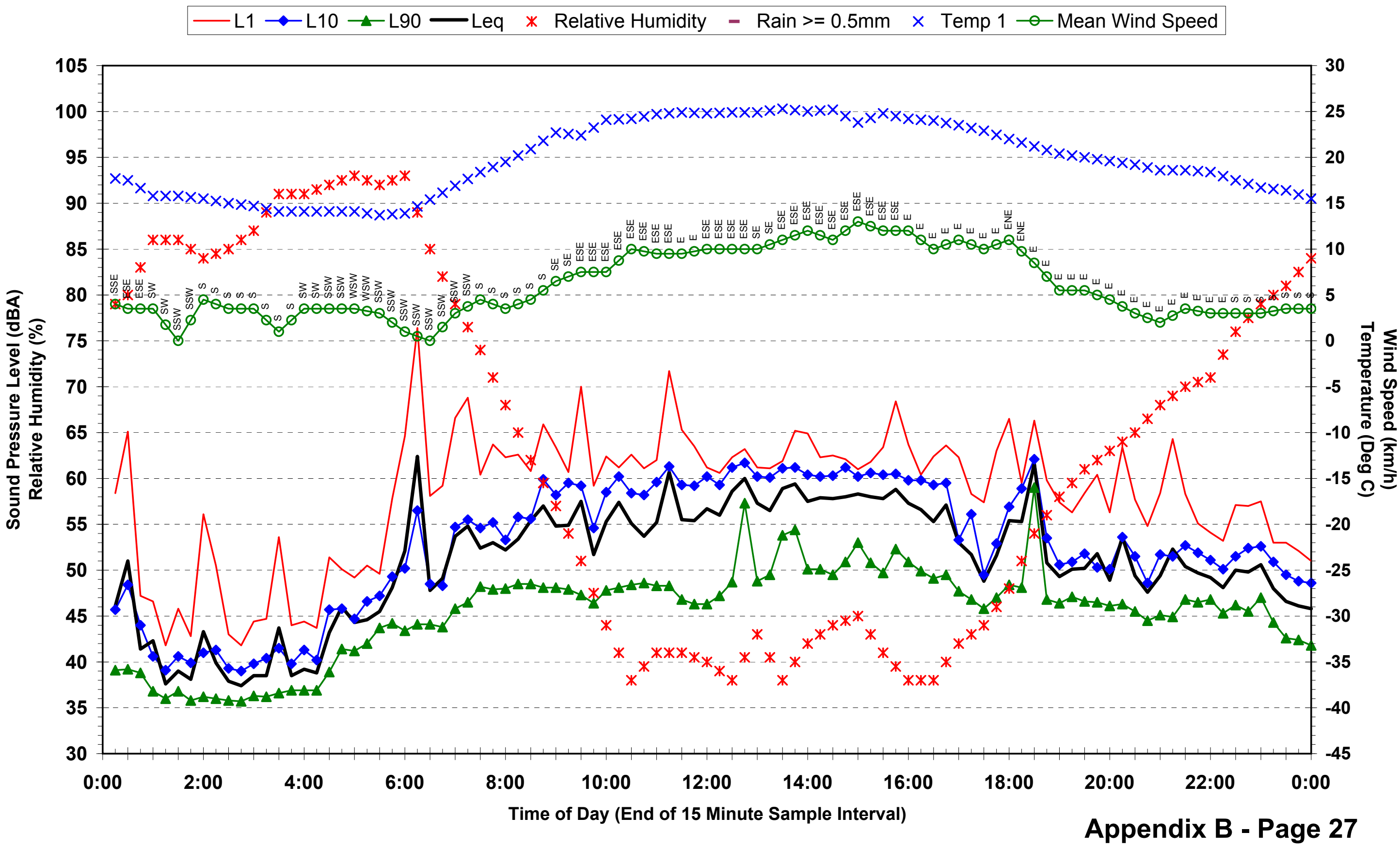
Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Monday 12 November 2007



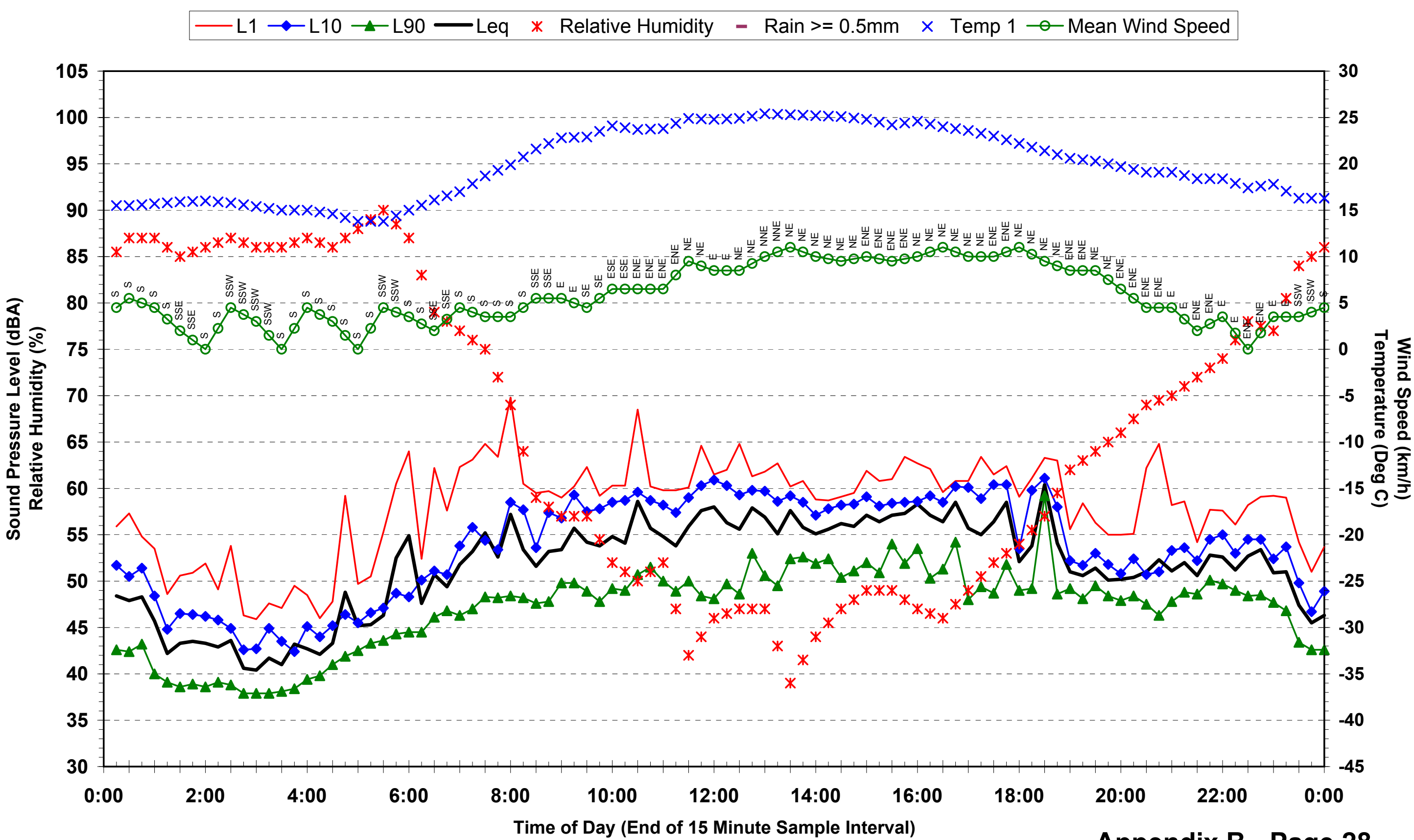
Appendix B - Page 26

Ambient Conditions
Heggies Report 20-1854

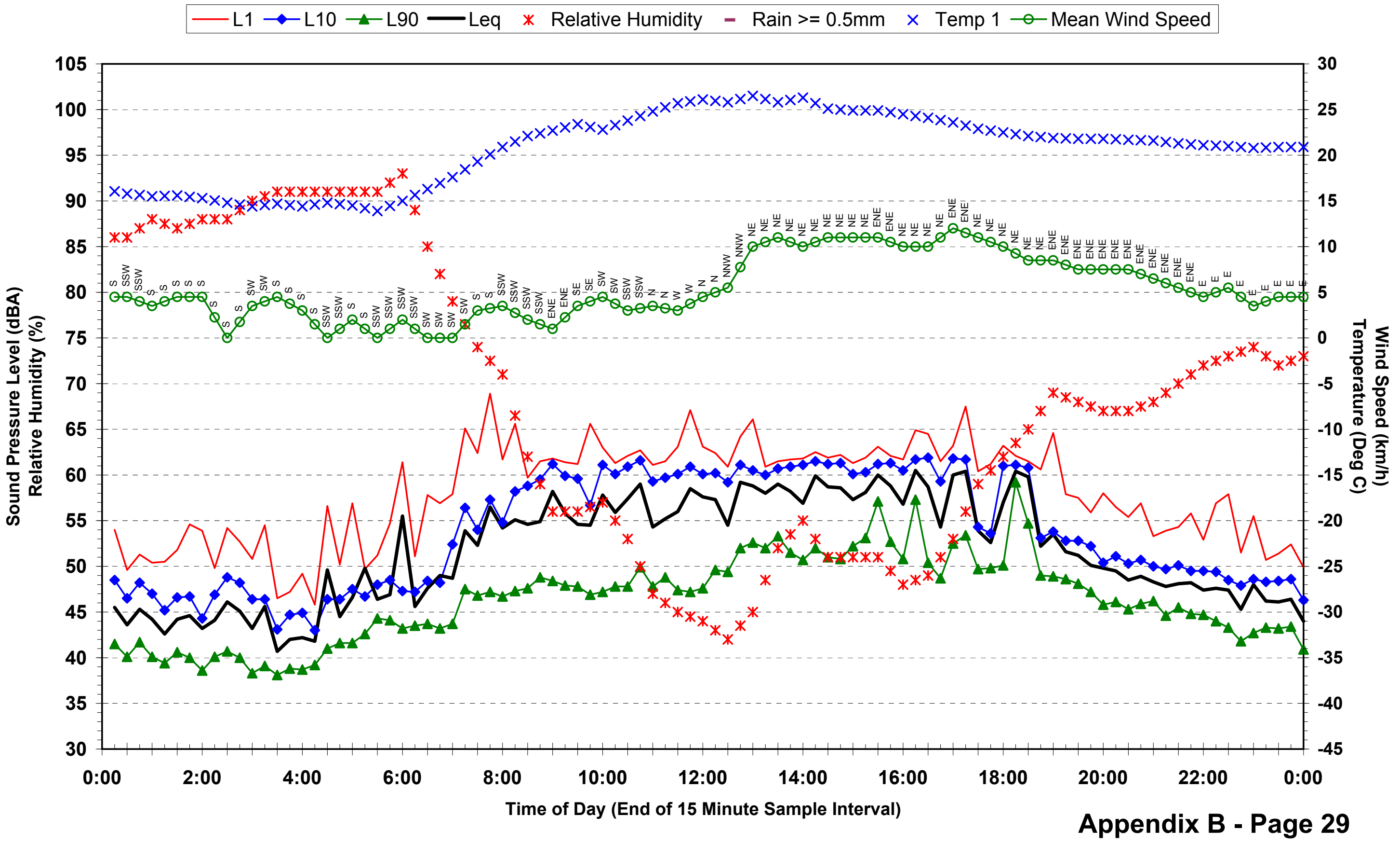
Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Tuesday 13 November 2007



Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Wednesday 14 November 2007

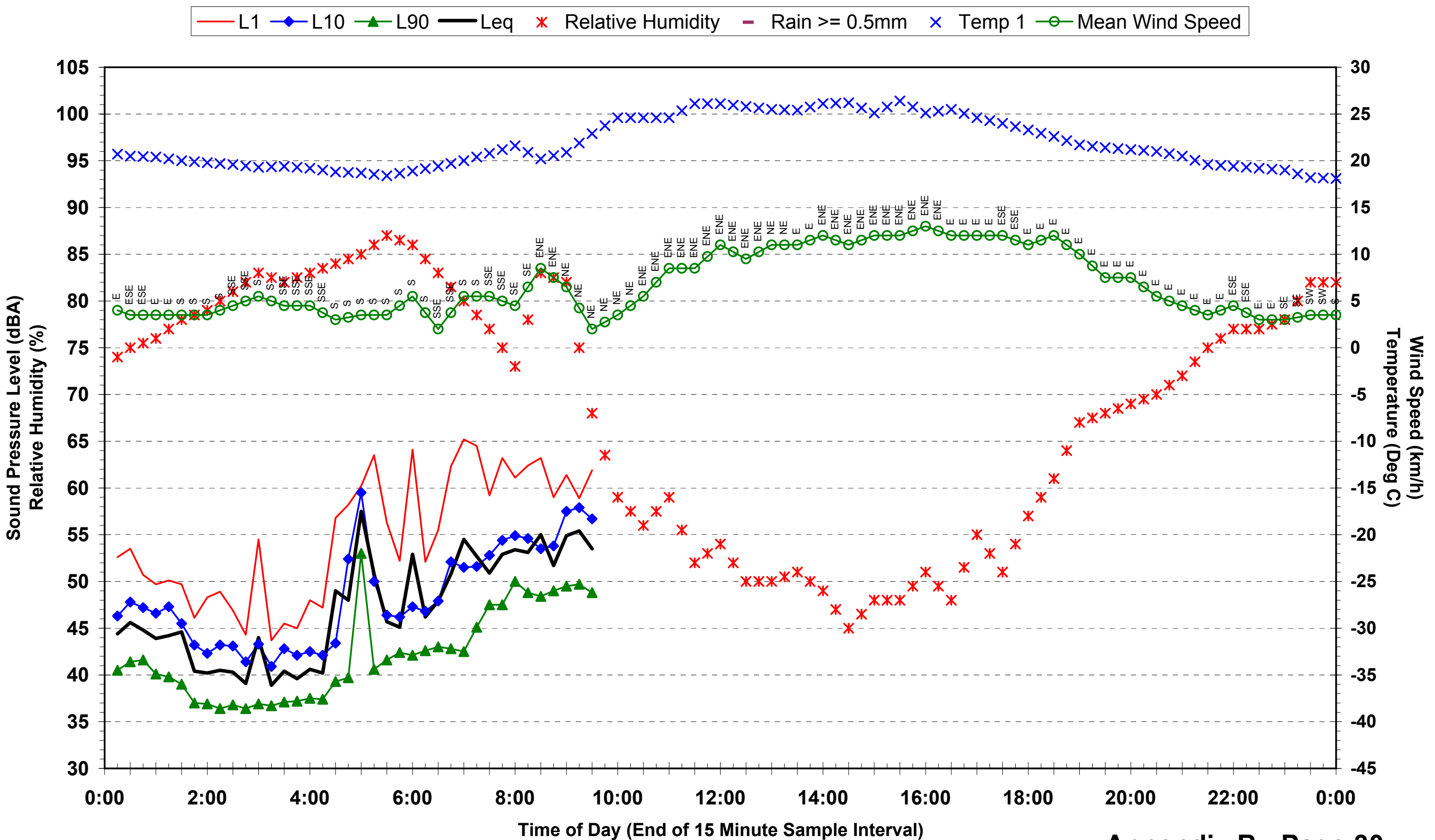


Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Thursday 15 November 2007



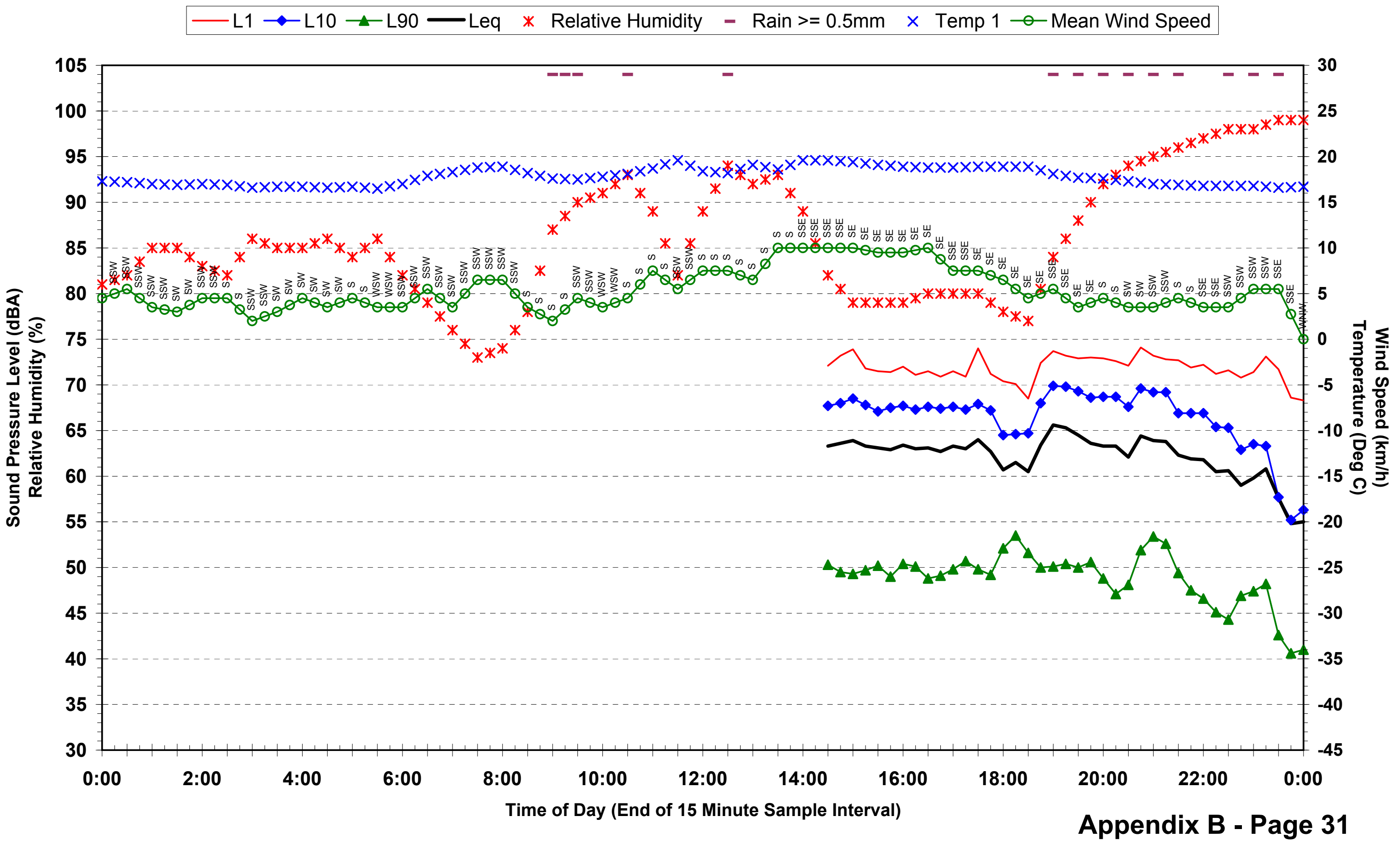
Appendix B - Page 29
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 3 - 6 Wool Street, Toowong - Friday 16 November 2007



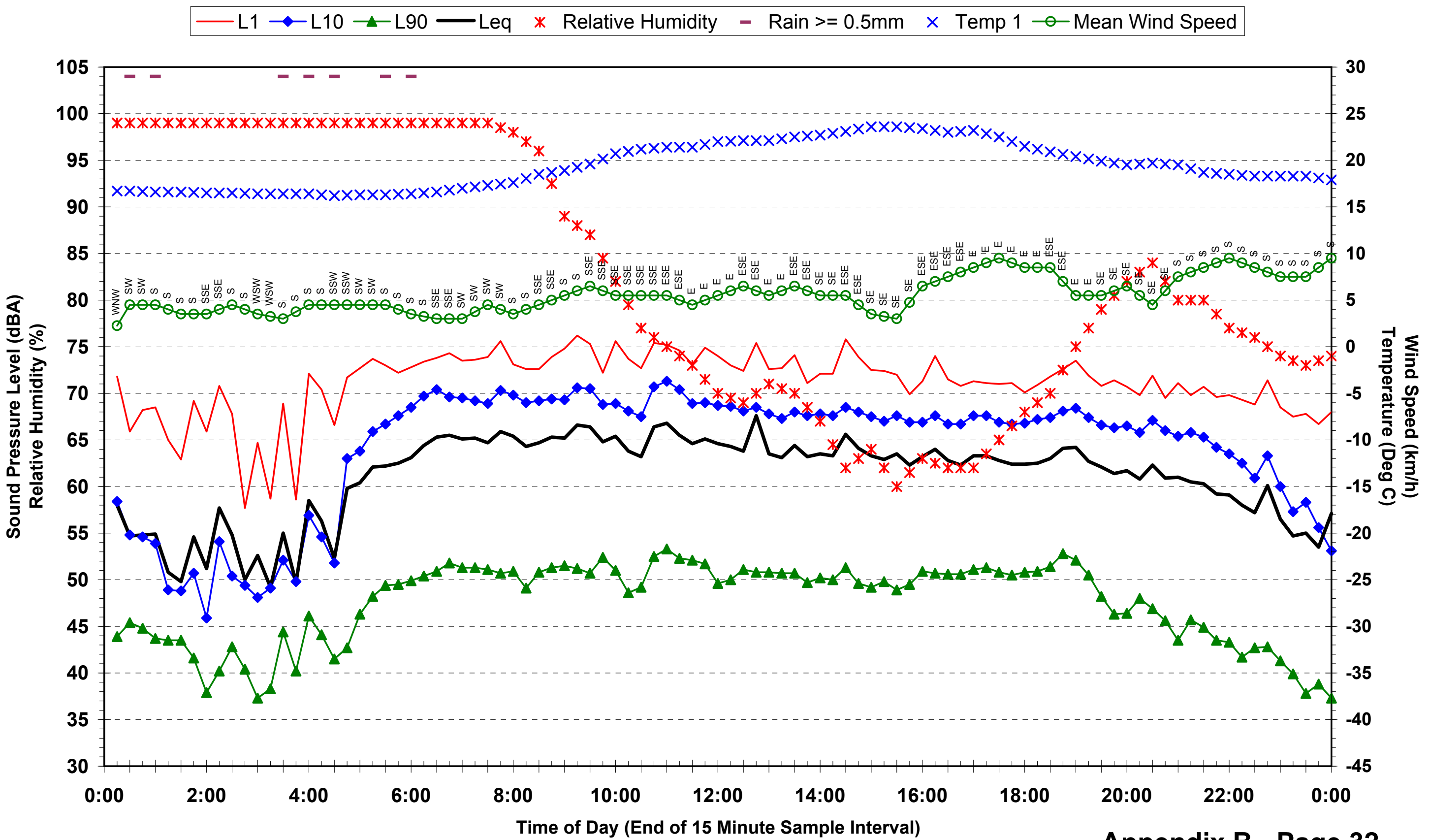
Appendix B - Page 30
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Wednesday 7 November 2007



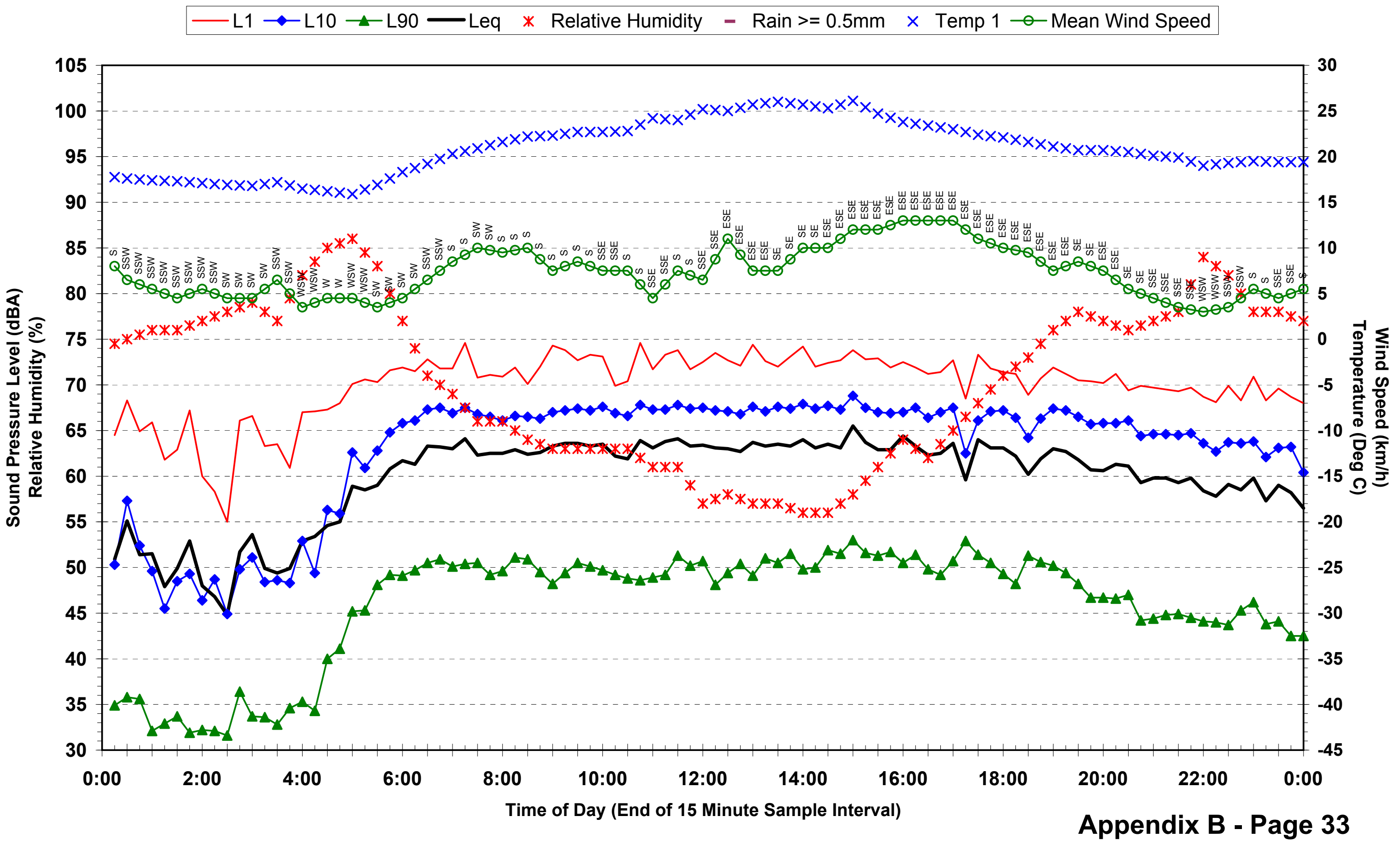
Appendix B - Page 31
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Thursday 8 November 2007



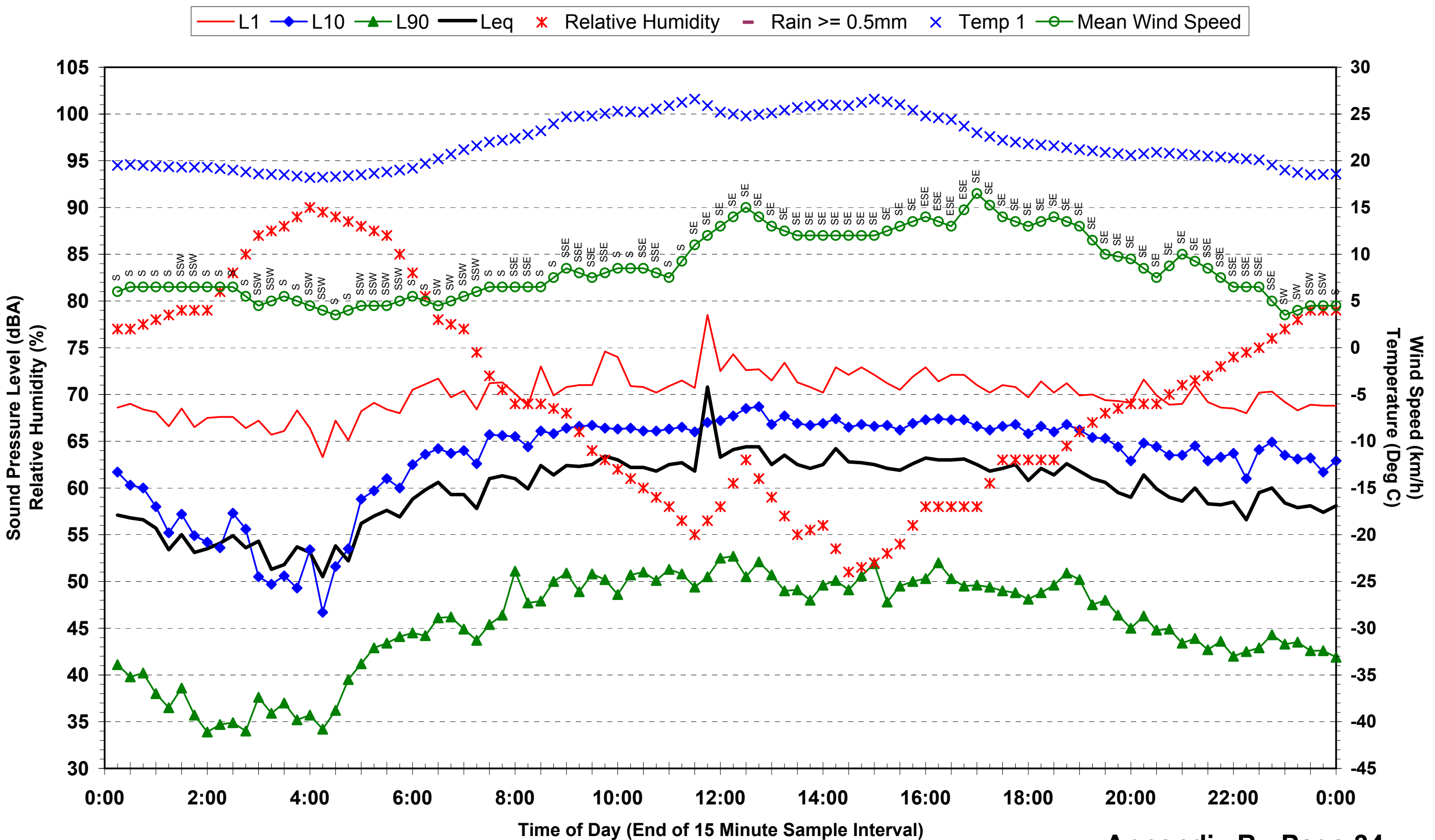
Appendix B - Page 32
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Friday 9 November 2007



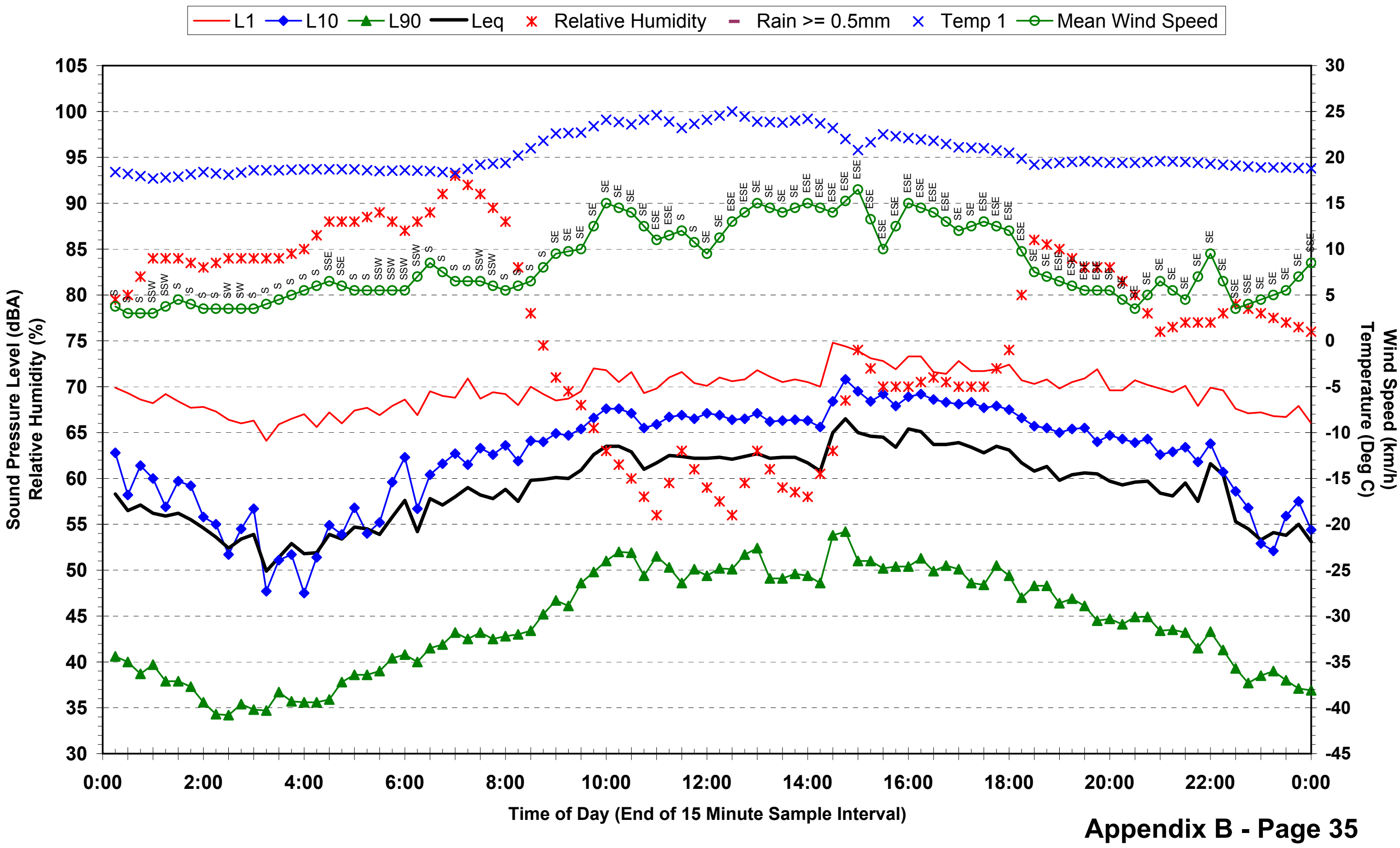
Appendix B - Page 33
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Saturday 10 November 2007



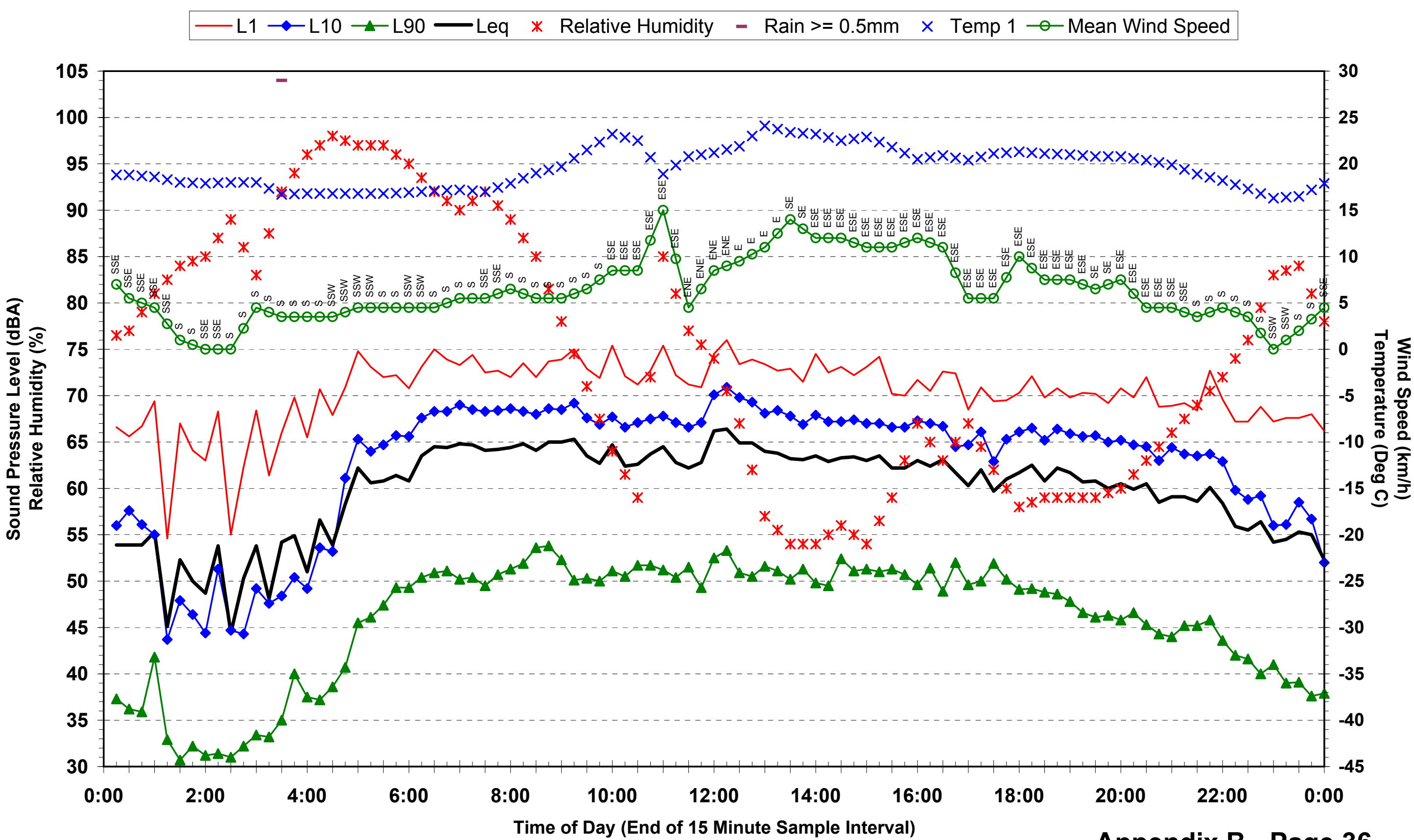
Appendix B - Page 34
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Sunday 11 November 2007



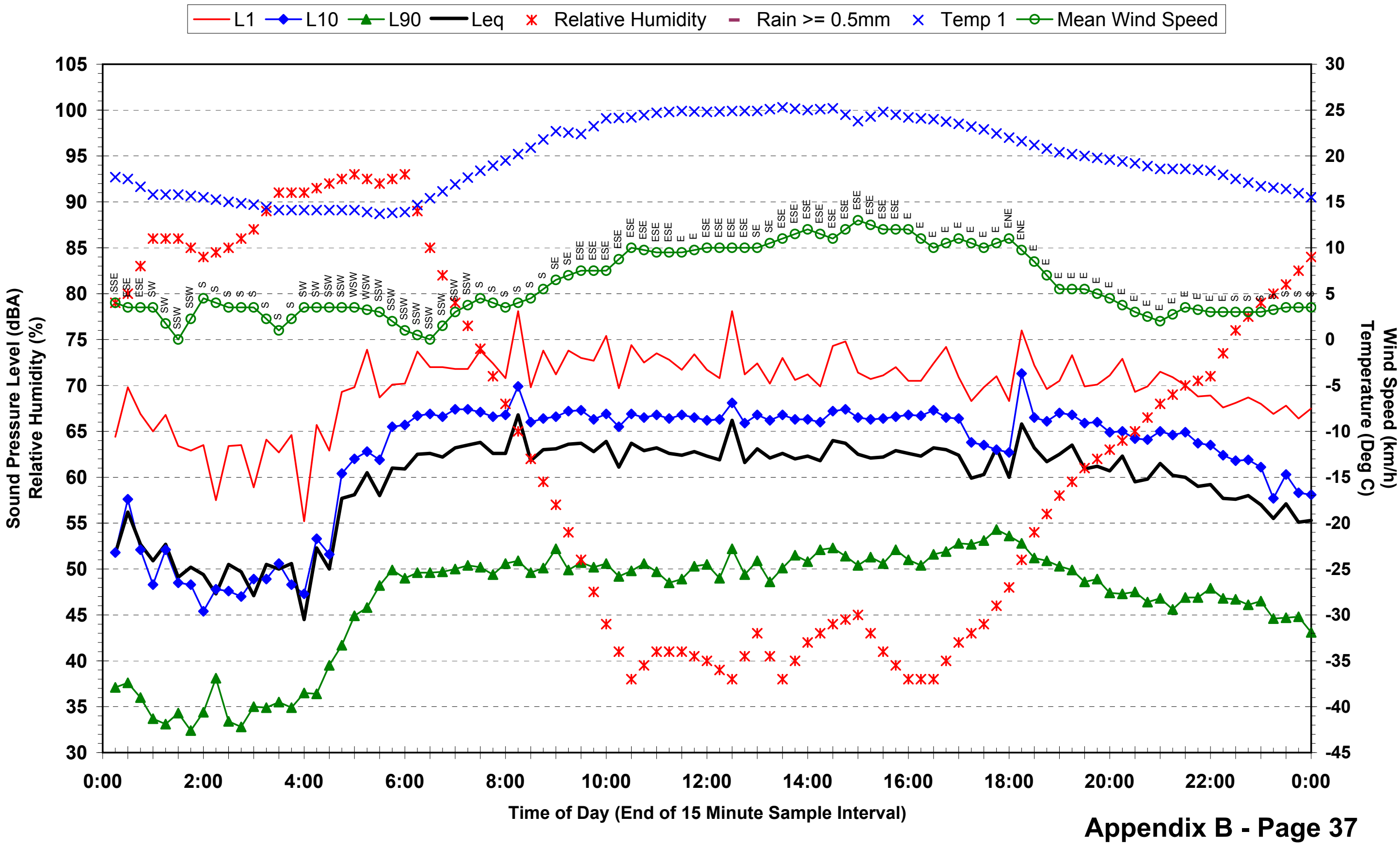
Appendix B - Page 35
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Monday 12 November 2007

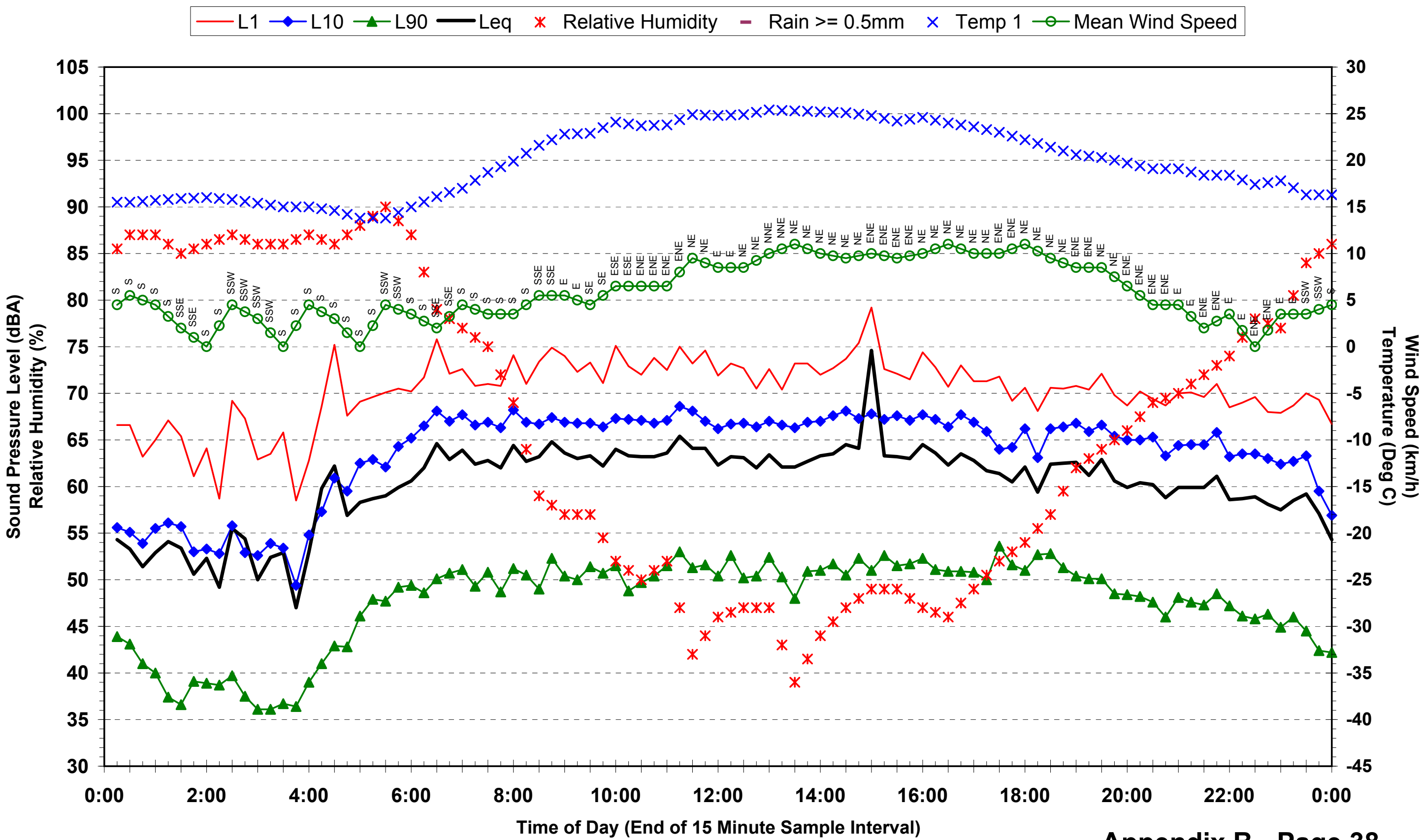


Appendix B - Page 36
Ambient Conditions
Heggies Report 20-1854

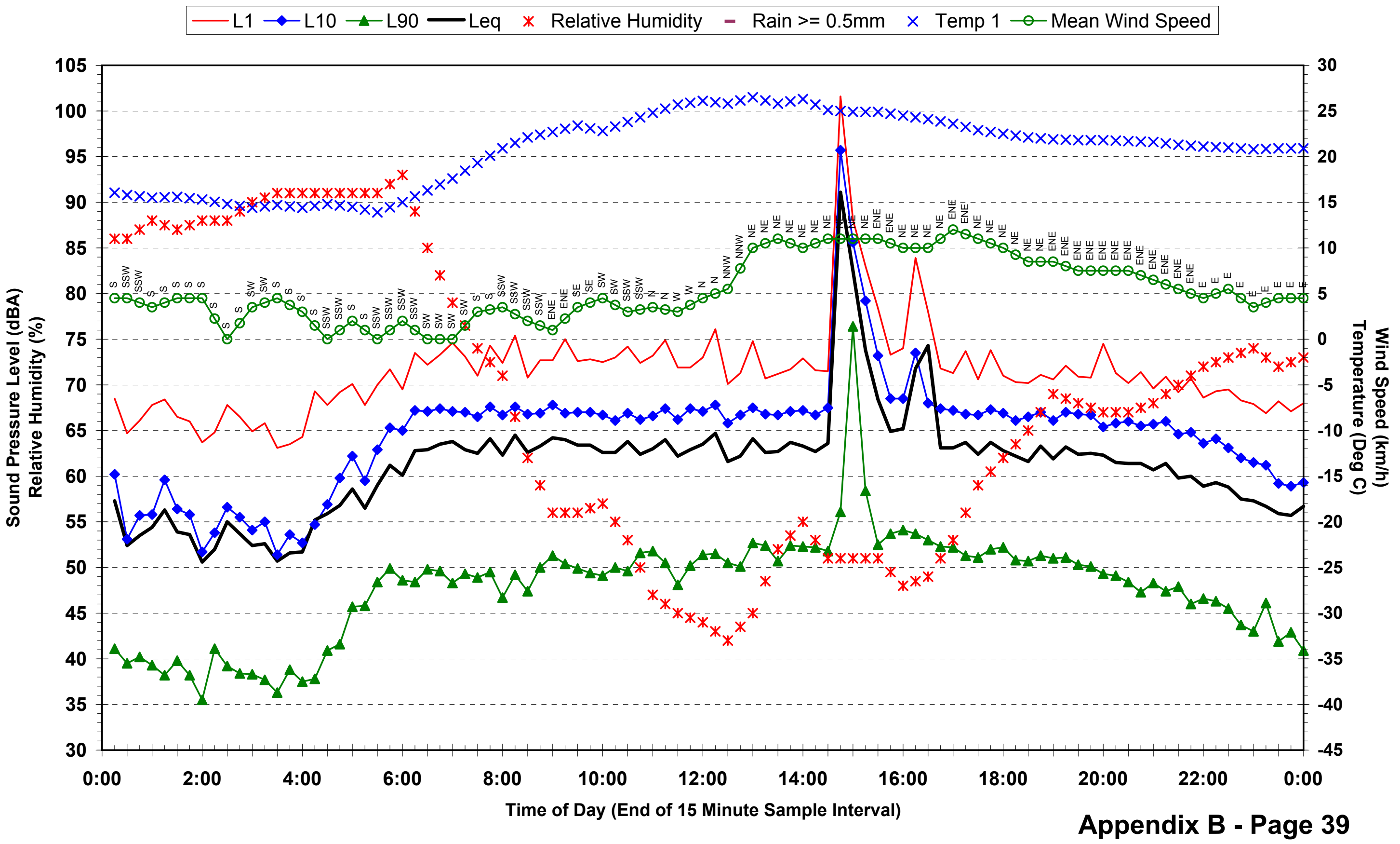
Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Tuesday 13 November 2007



Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Wednesday 14 November 2007



Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Thursday 15 November 2007

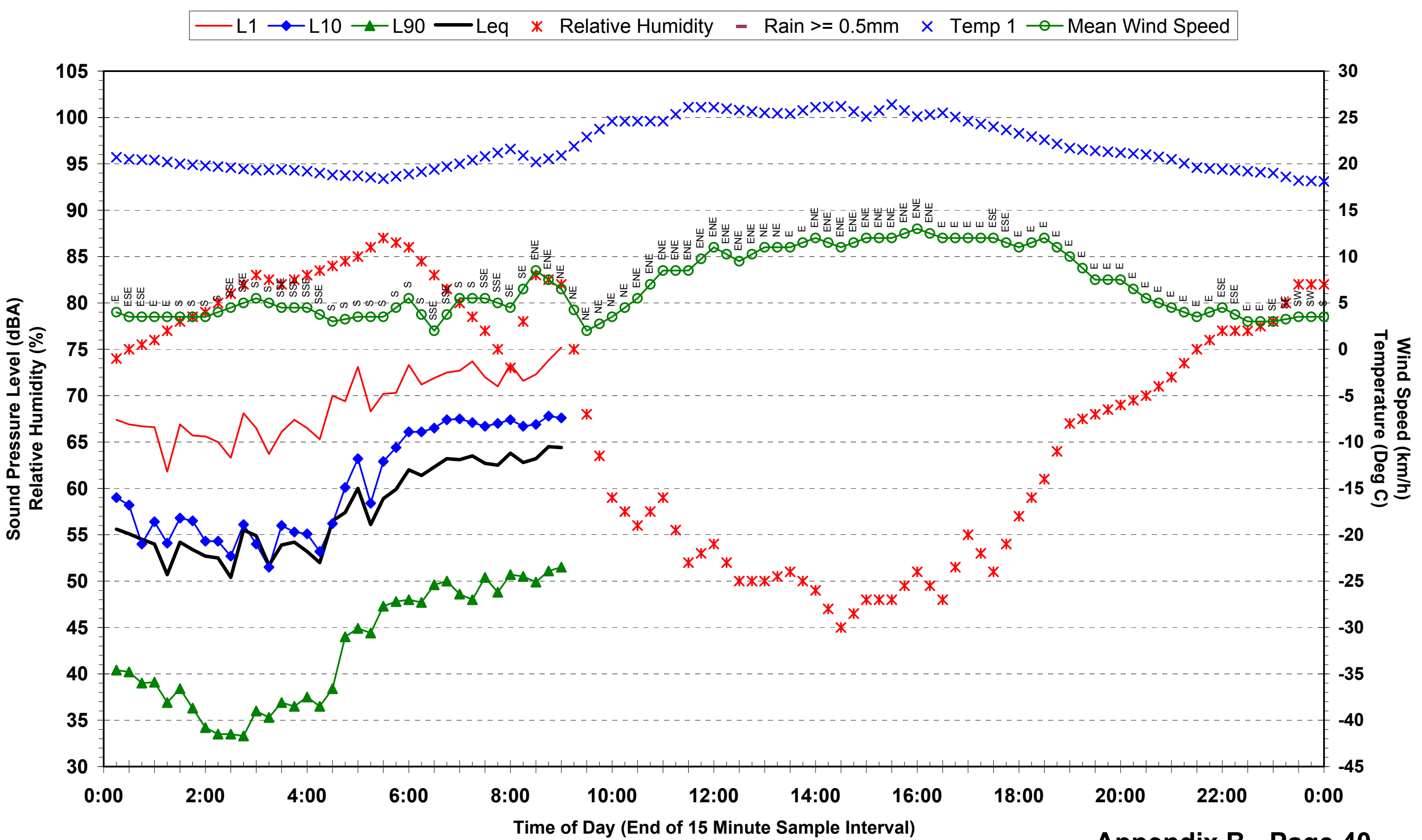


Appendix B - Page 39

Ambient Conditions

Heggies Report 20-1854

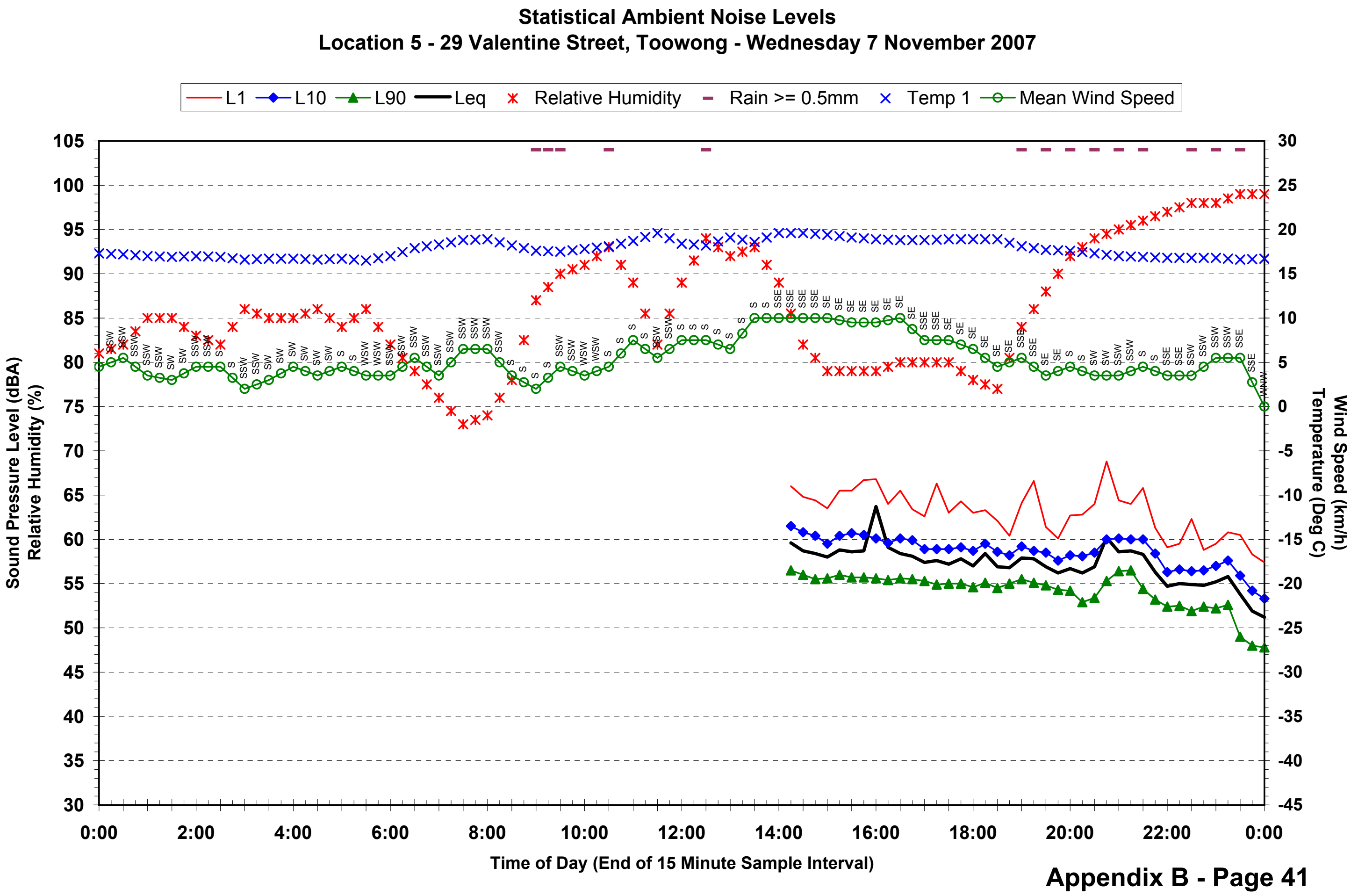
Statistical Ambient Noise Levels
Location 4 - 128 Sylvan Road, Toowong - Friday 16 November 2007



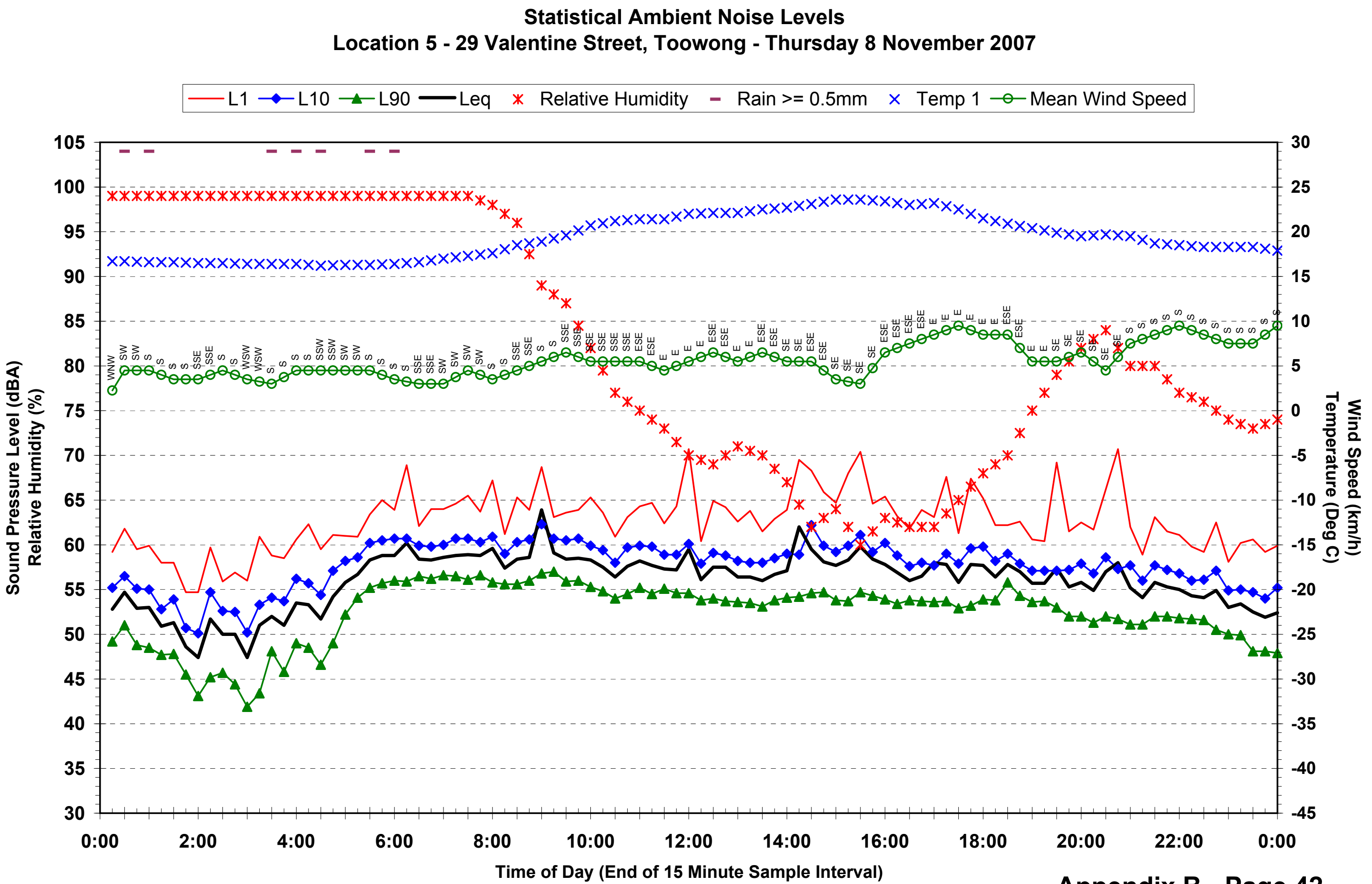
Appendix B - Page 40

Ambient Conditions

Heggies Report 20-1854

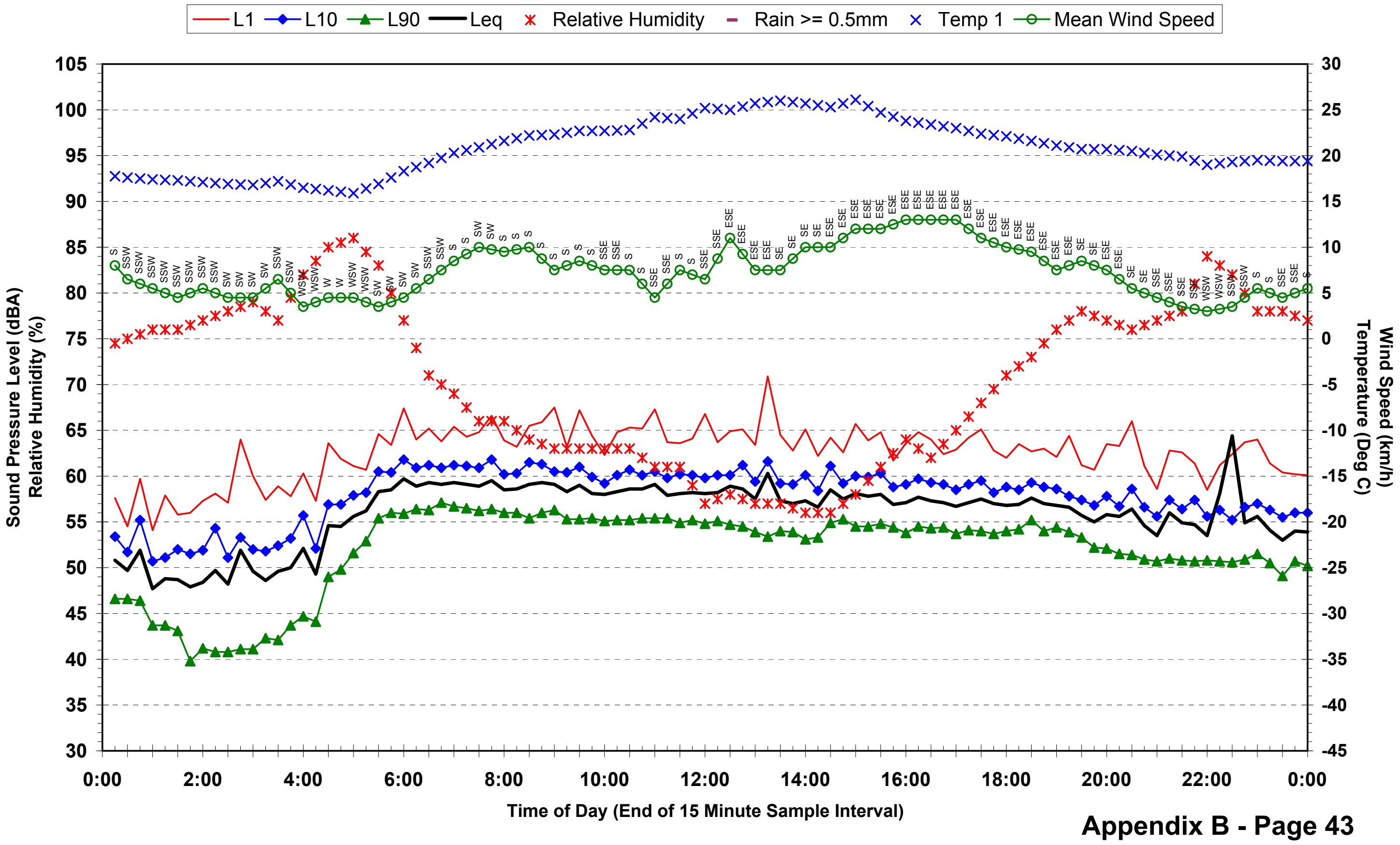


Appendix B - Page 41
Ambient Conditions
Heggies Report 20-1854



Appendix B - Page 42
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Friday 9 November 2007

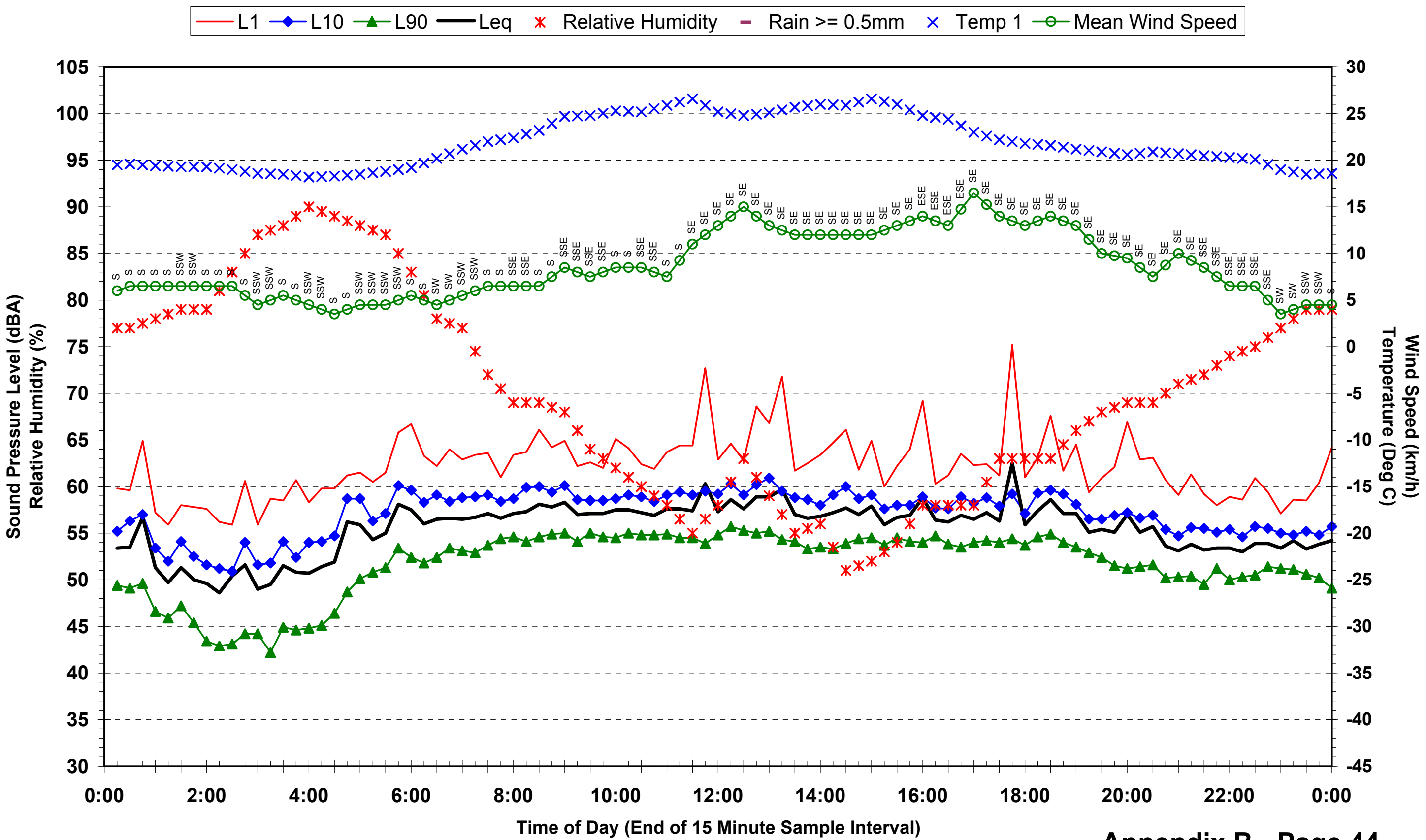


Appendix B - Page 43

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Saturday 10 November 2007

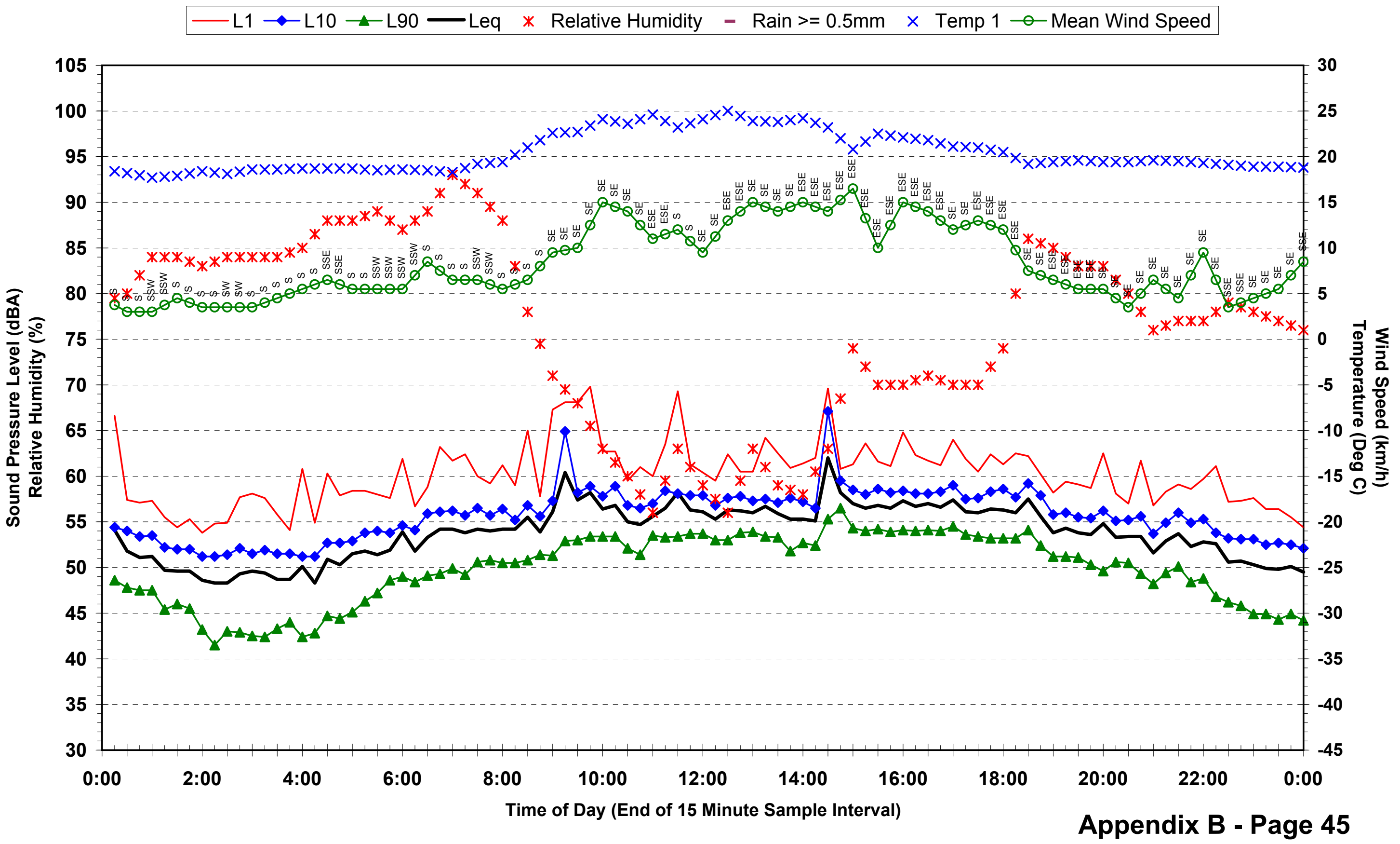


Appendix B - Page 44

Ambient Conditions

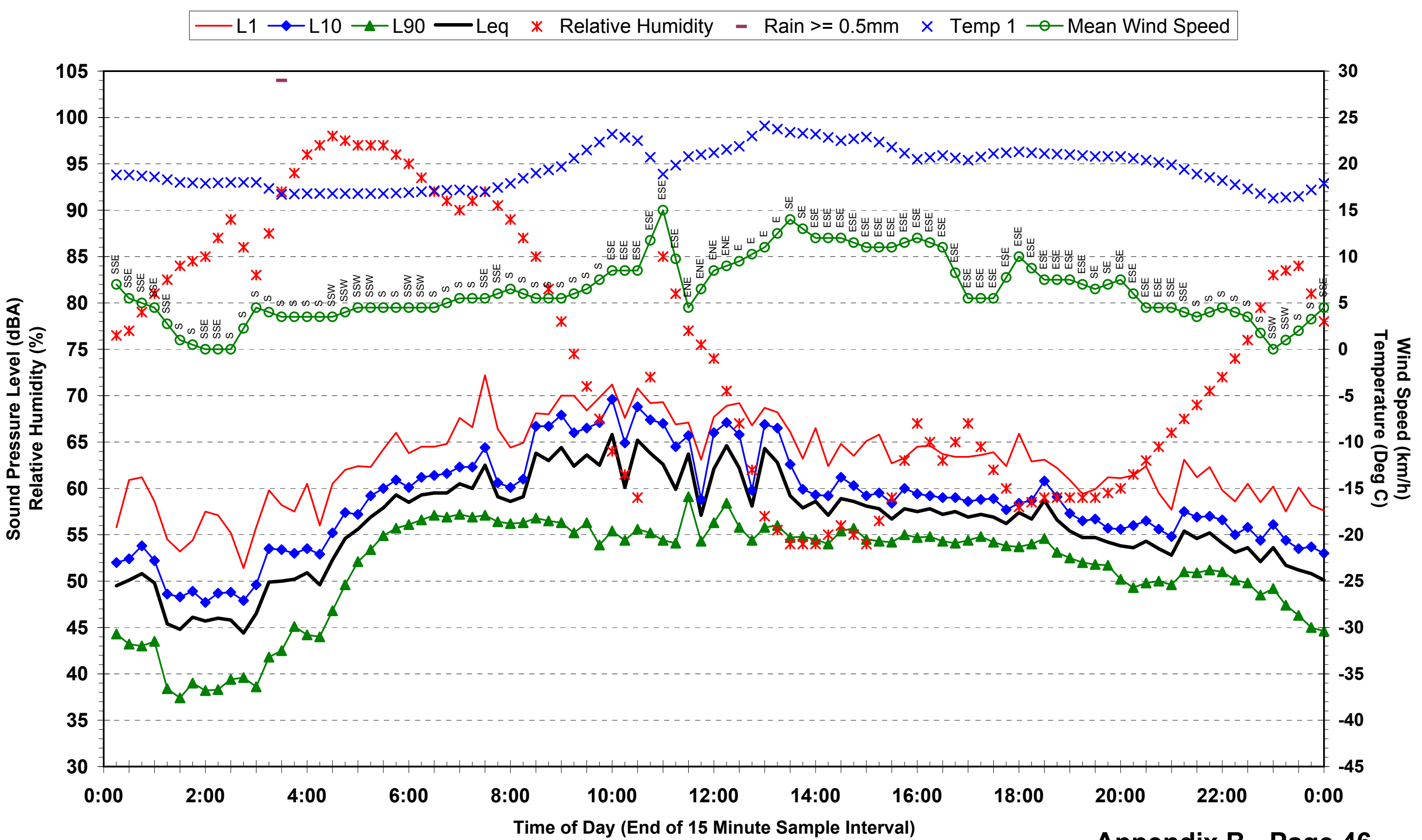
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Sunday 11 November 2007



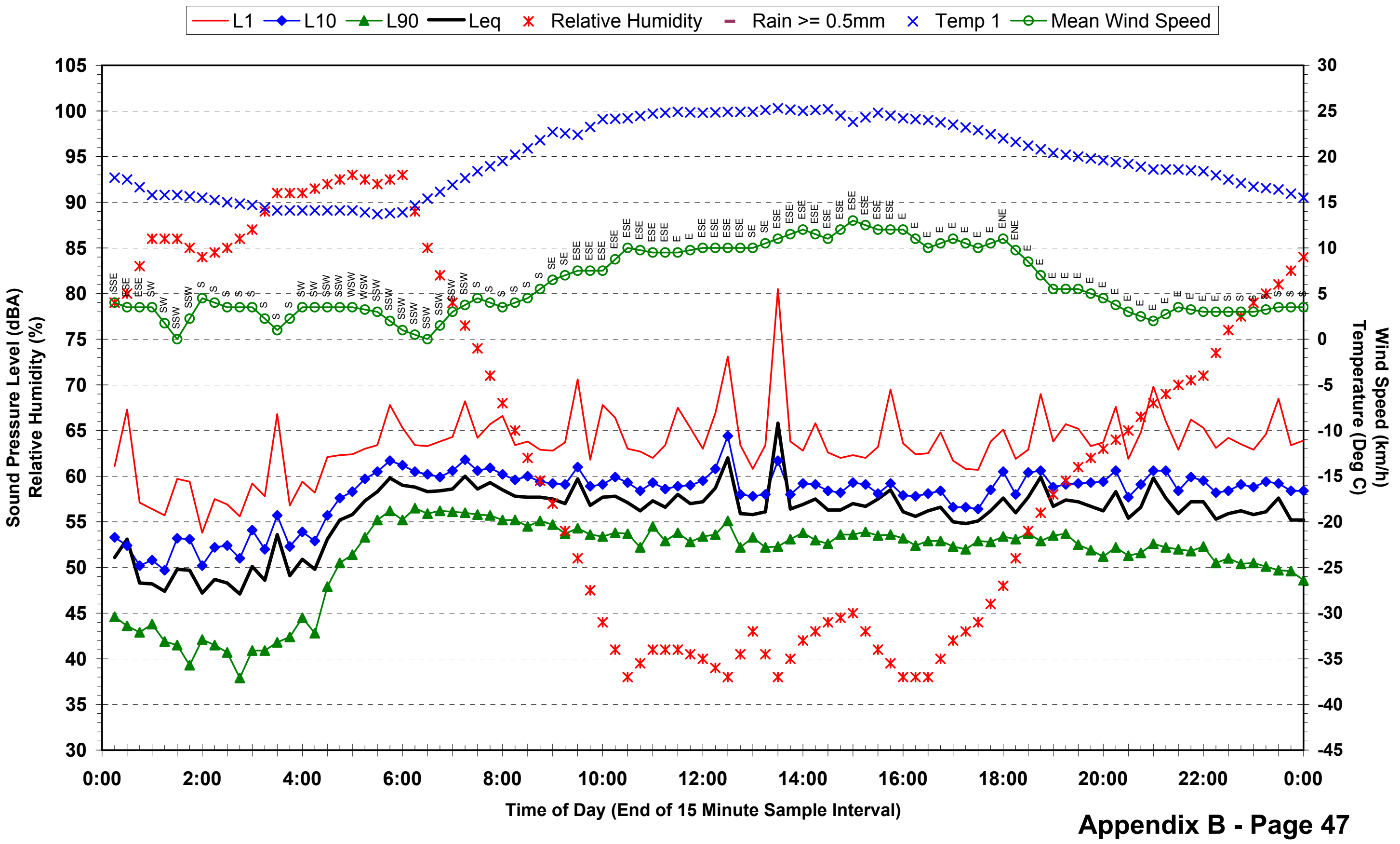
Appendix B - Page 45
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Monday 12 November 2007



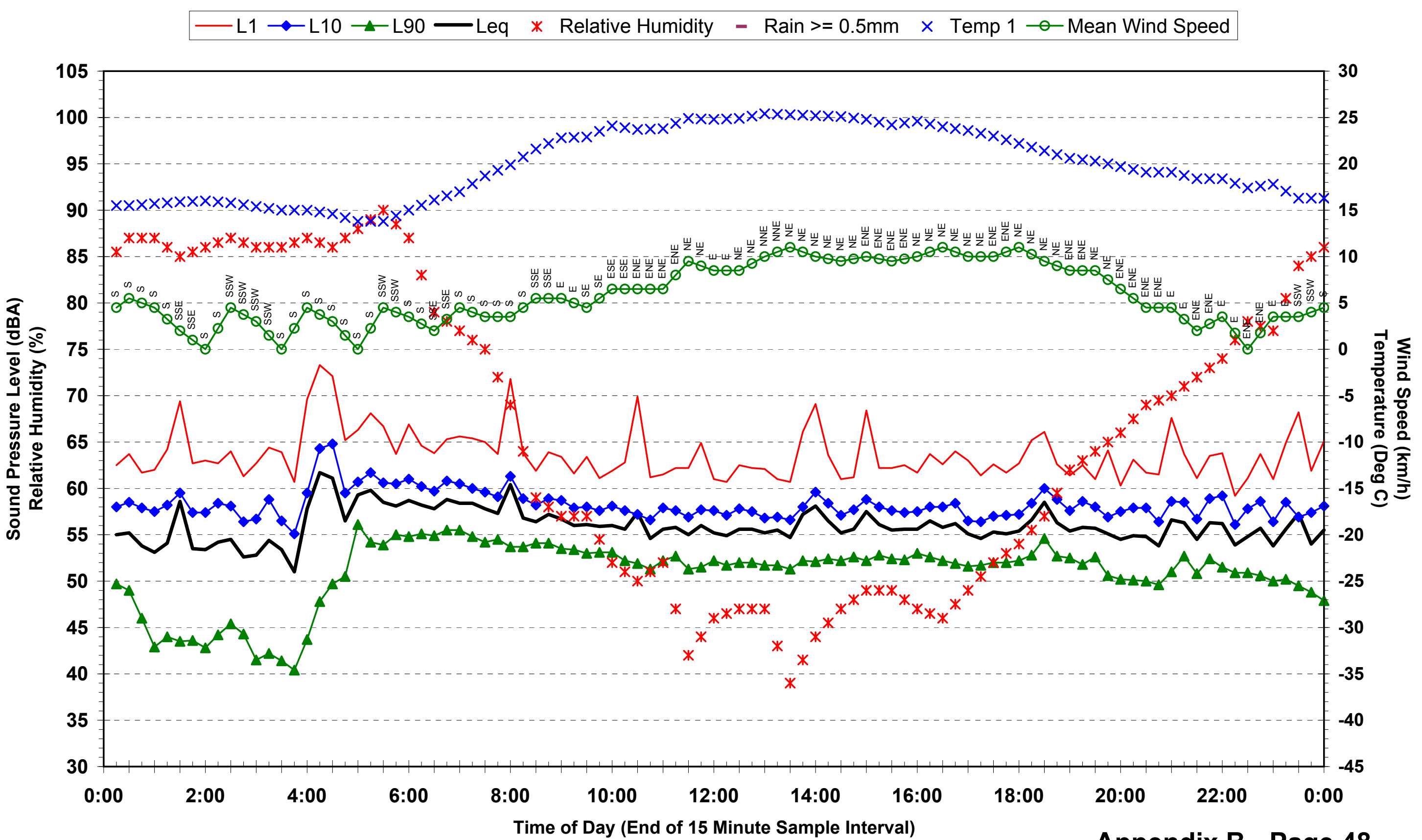
Appendix B - Page 46
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Tuesday 13 November 2007



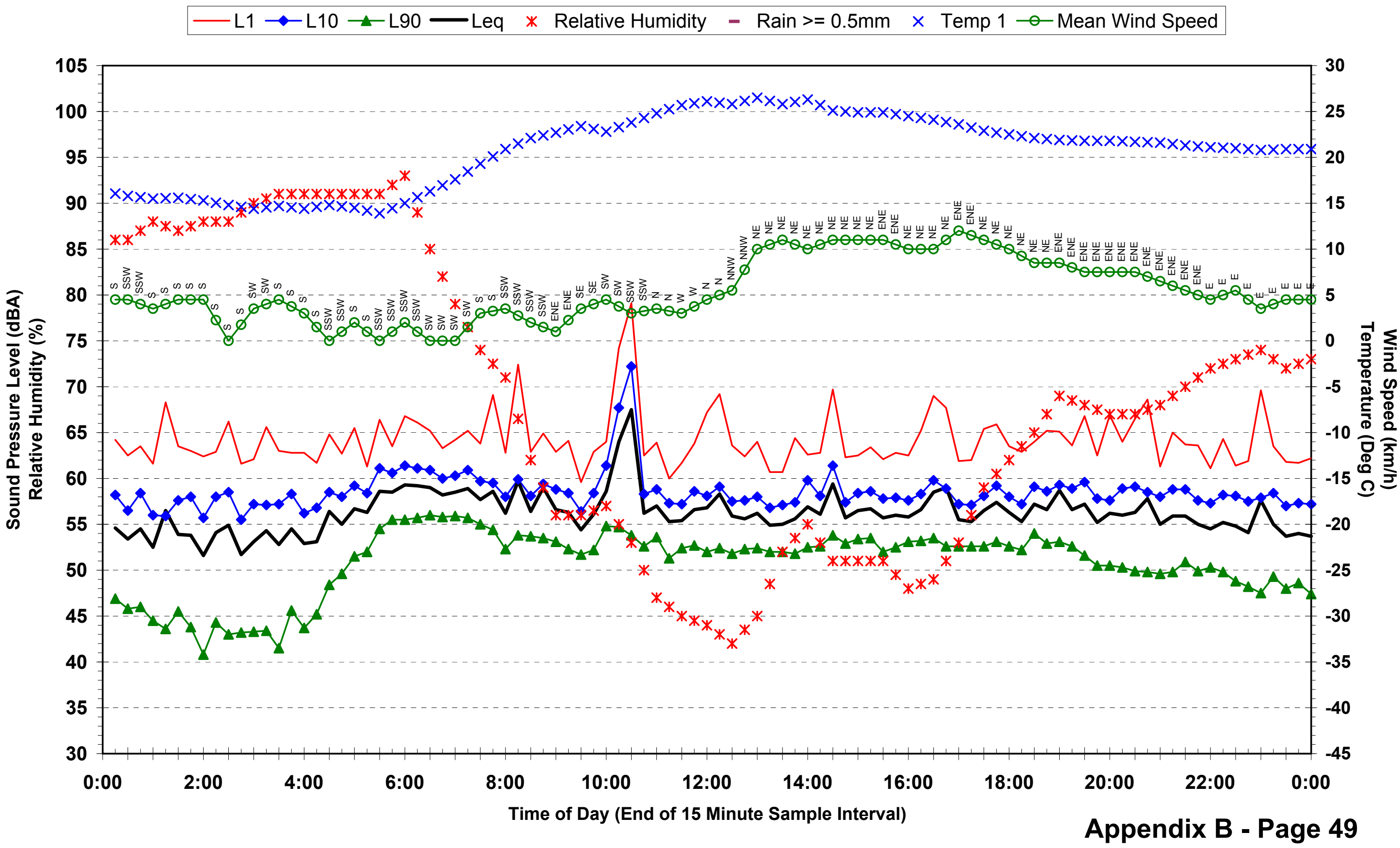
Appendix B - Page 47
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Wednesday 14 November 2007



Appendix B - Page 48
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Thursday 15 November 2007

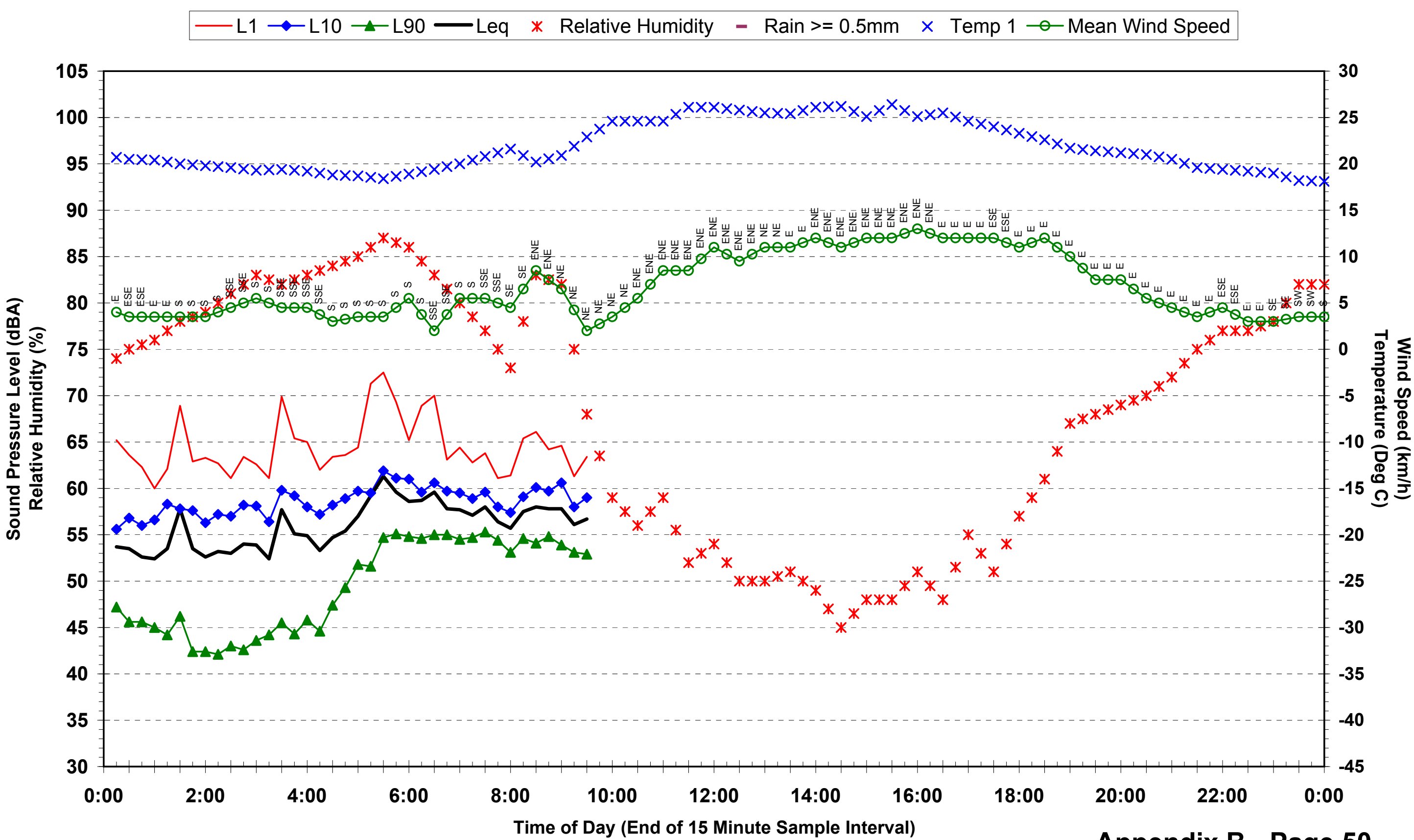


Appendix B - Page 49

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 5 - 29 Valentine Street, Toowong - Friday 16 November 2007

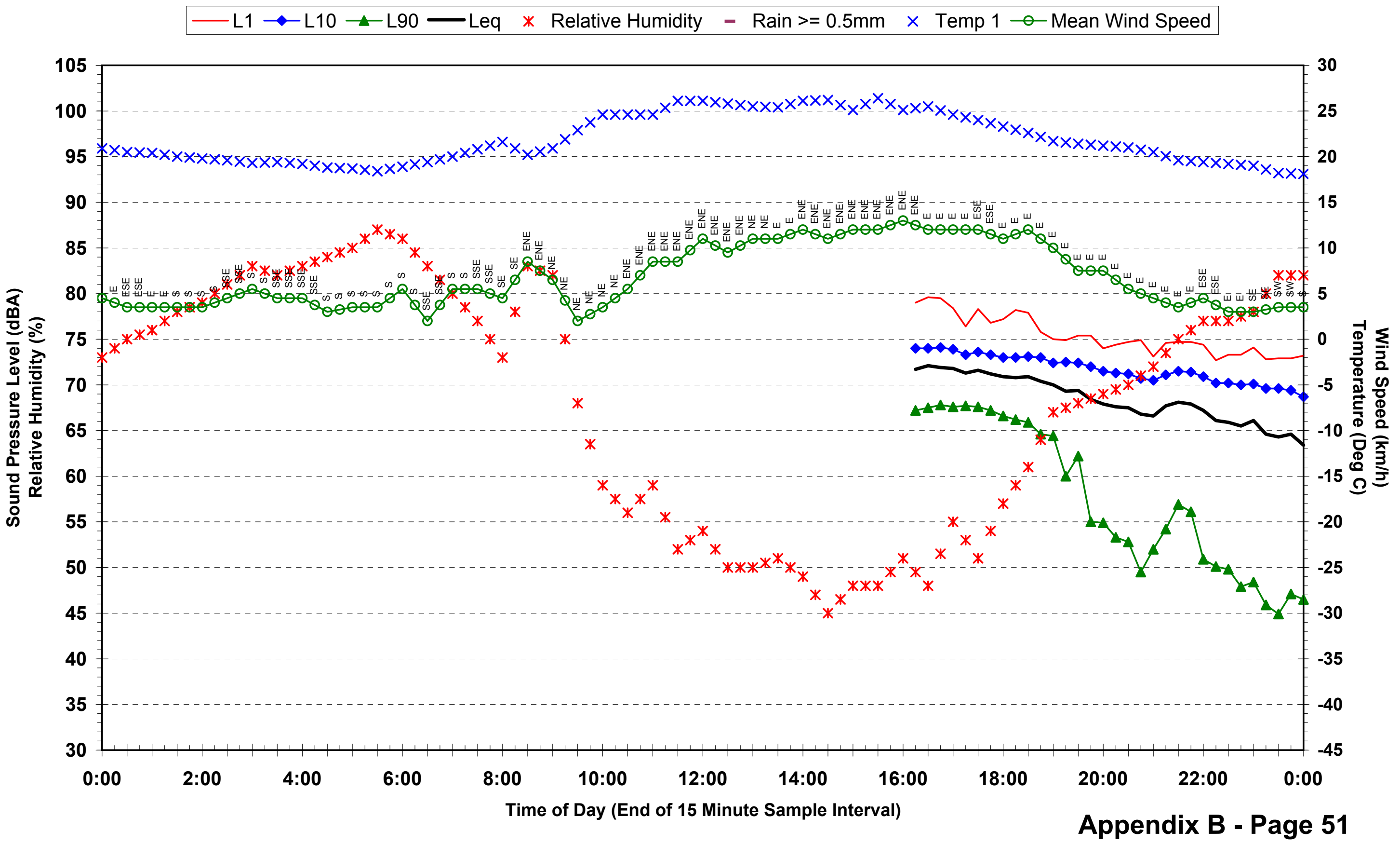


Appendix B - Page 50

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Friday 16 November 2007

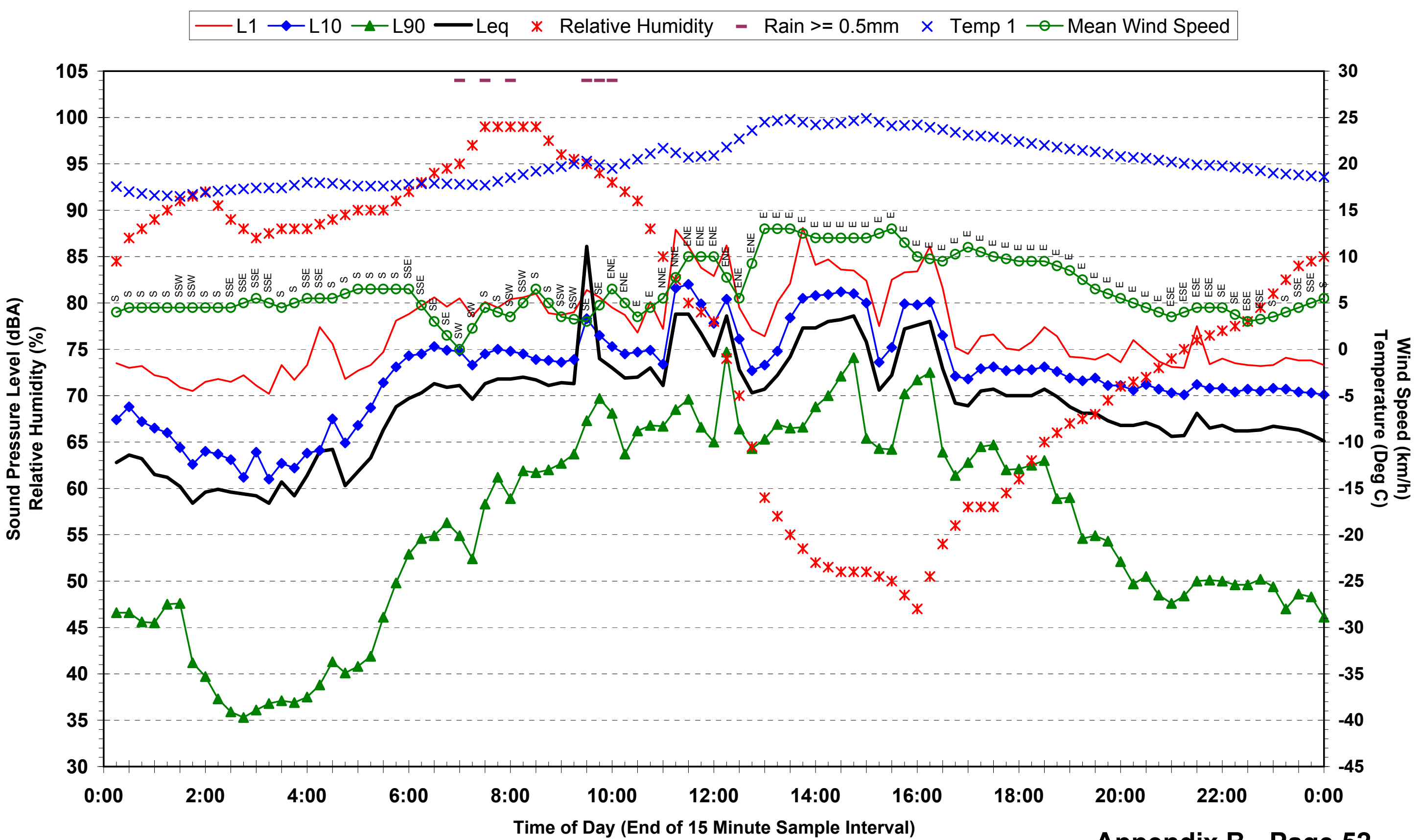


Appendix B - Page 51

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Saturday 17 November 2007

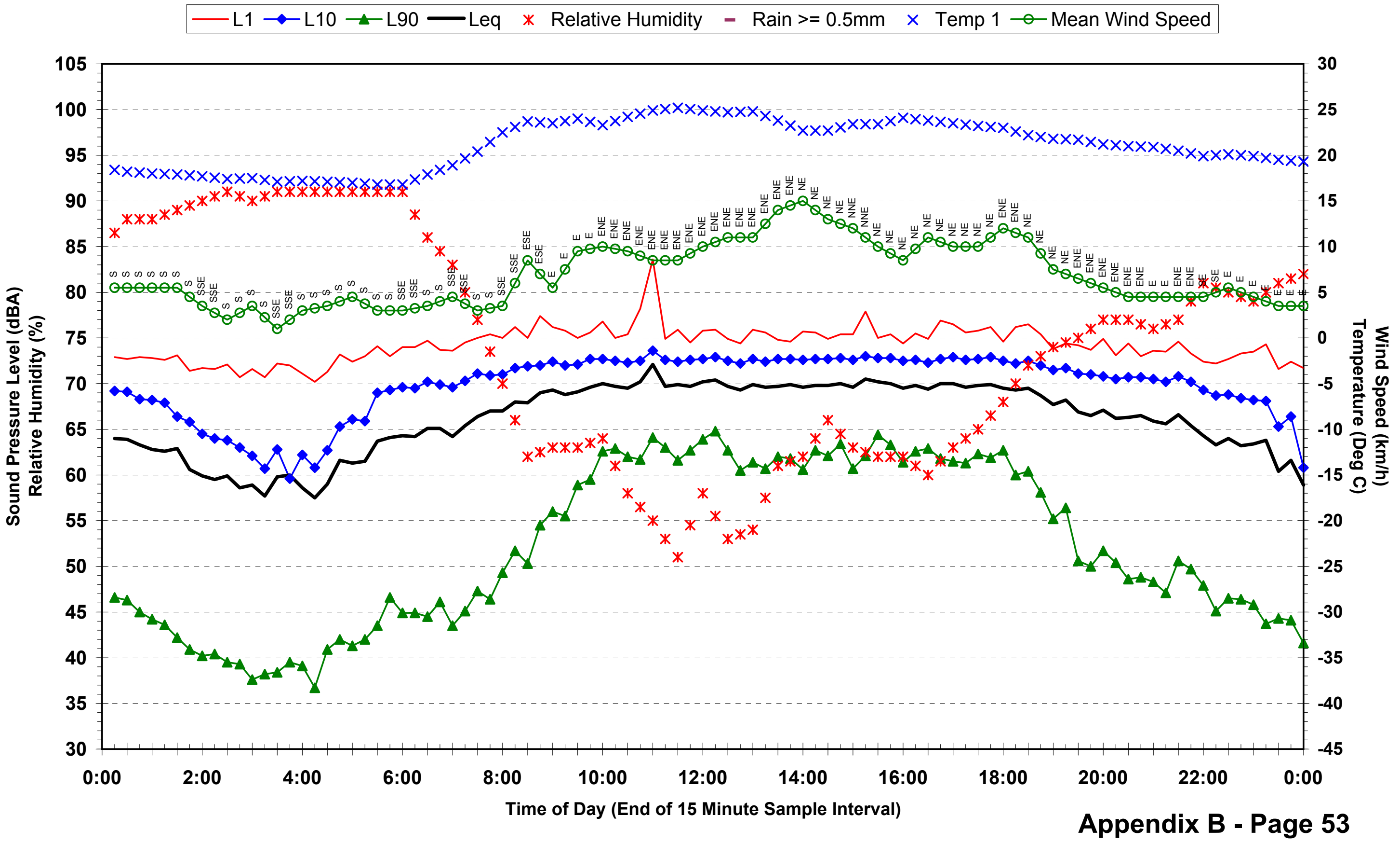


Appendix B - Page 52

Ambient Conditions

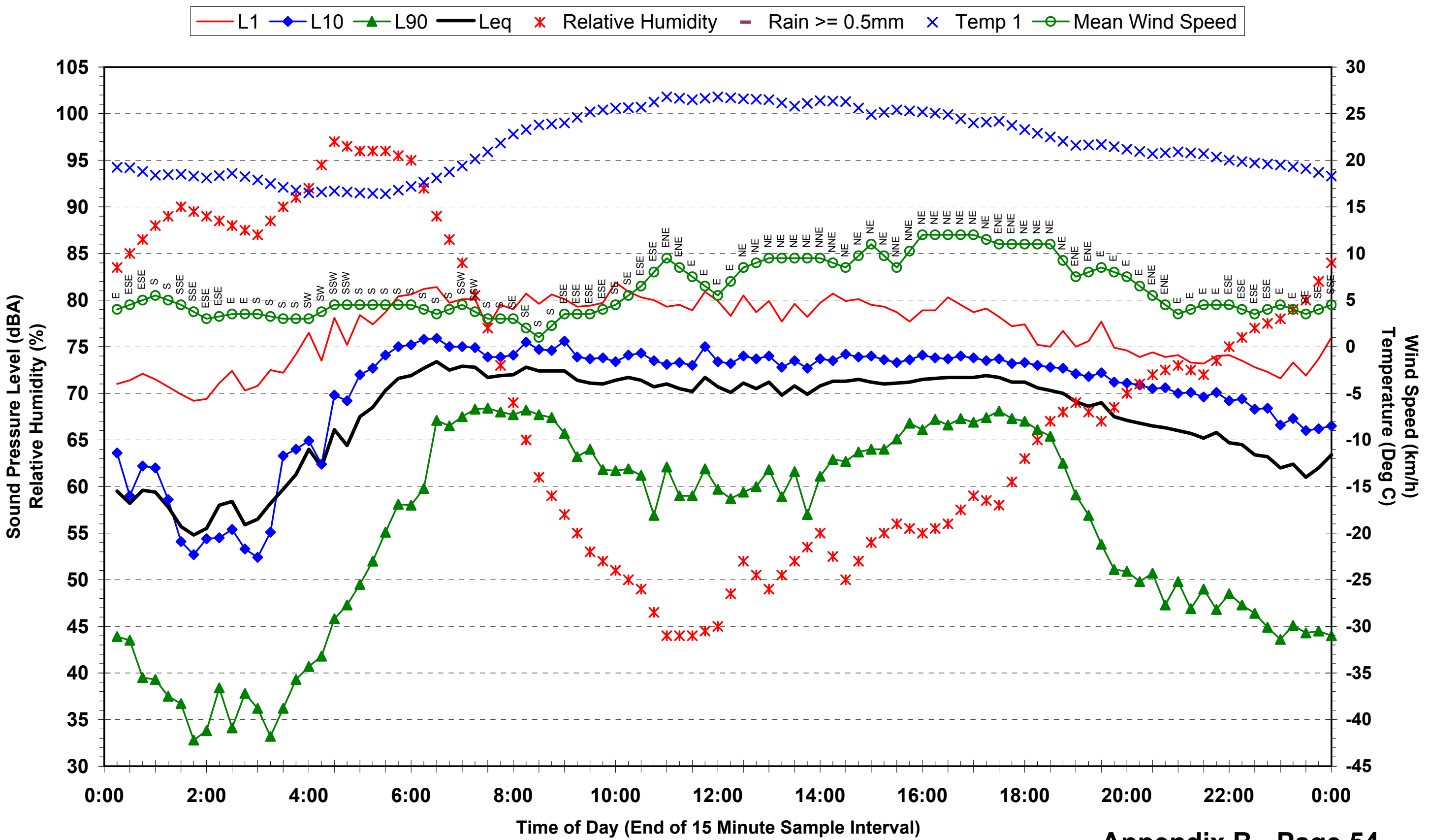
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Sunday 18 November 2007



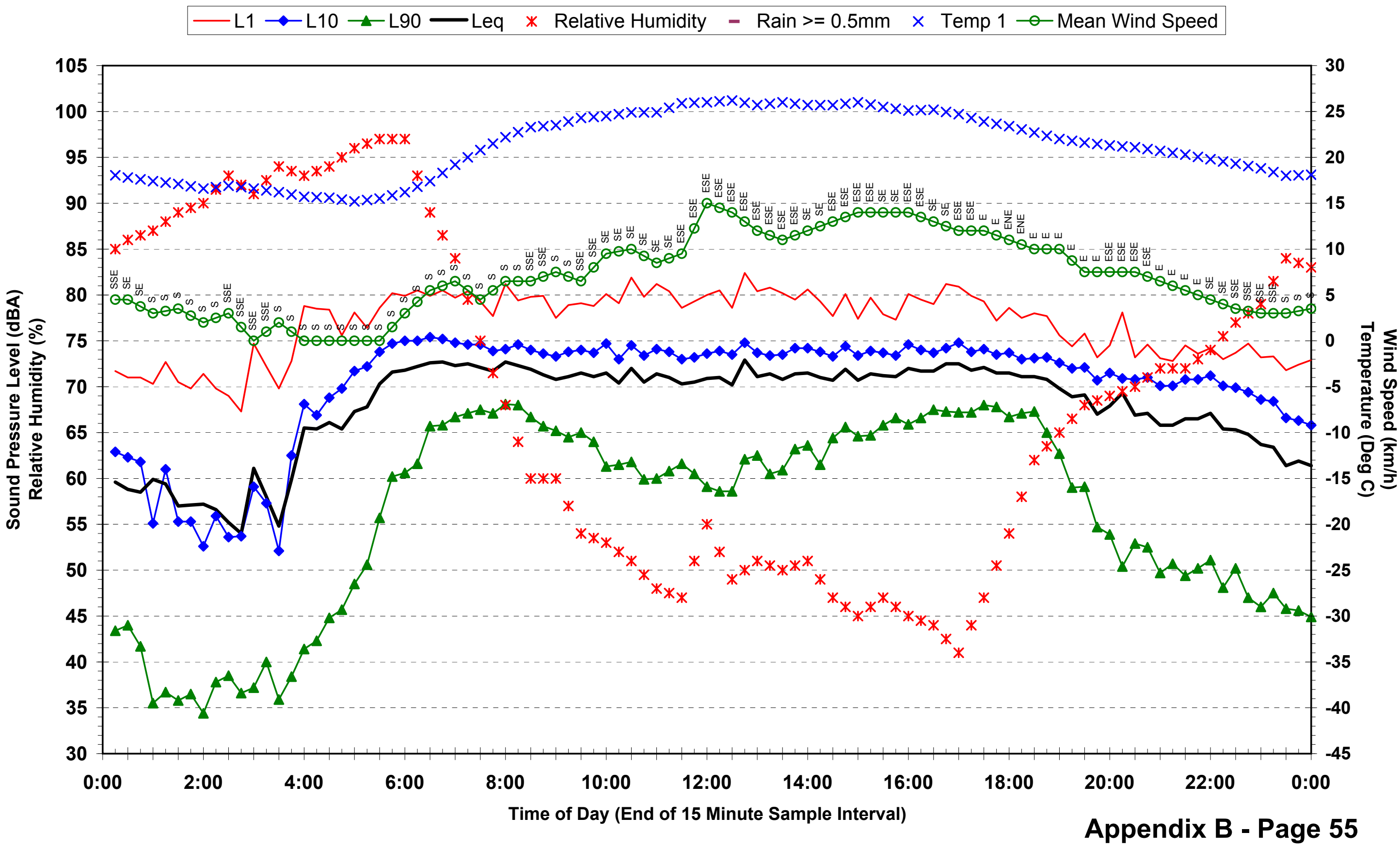
Appendix B - Page 53
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Monday 19 November 2007



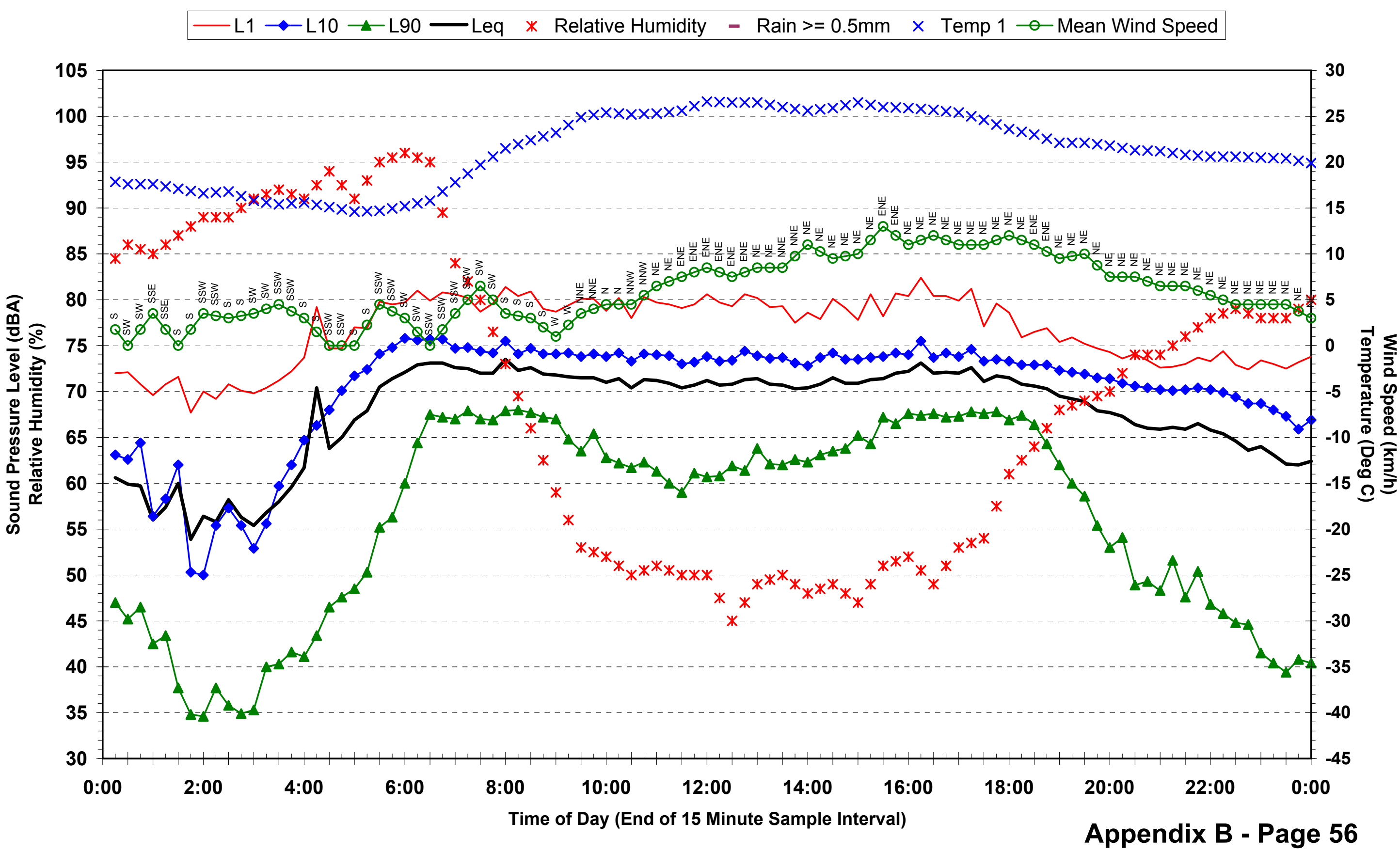
Appendix B - Page 54
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Tuesday 20 November 2007



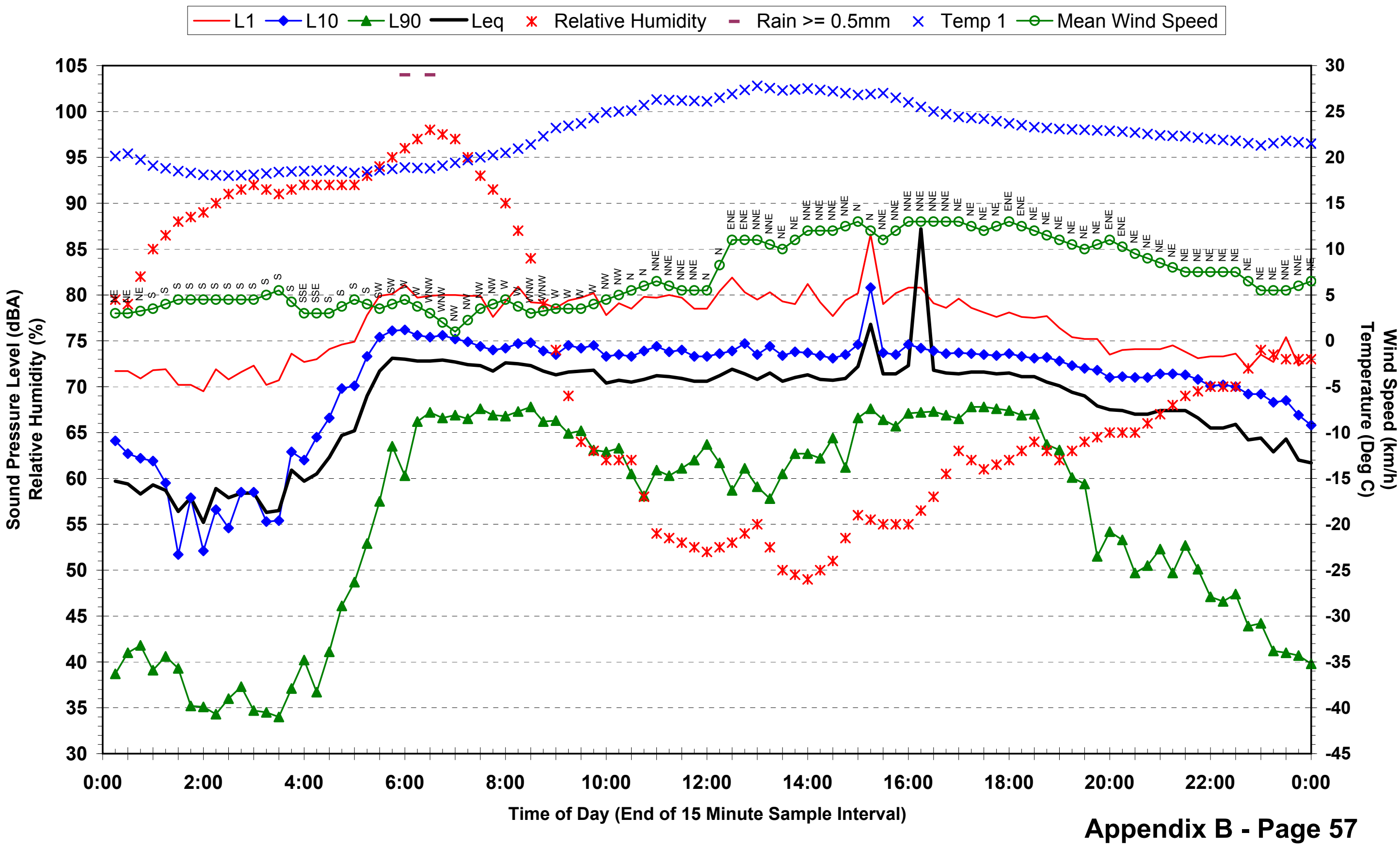
Appendix B - Page 55
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Wednesday 21 November 2007



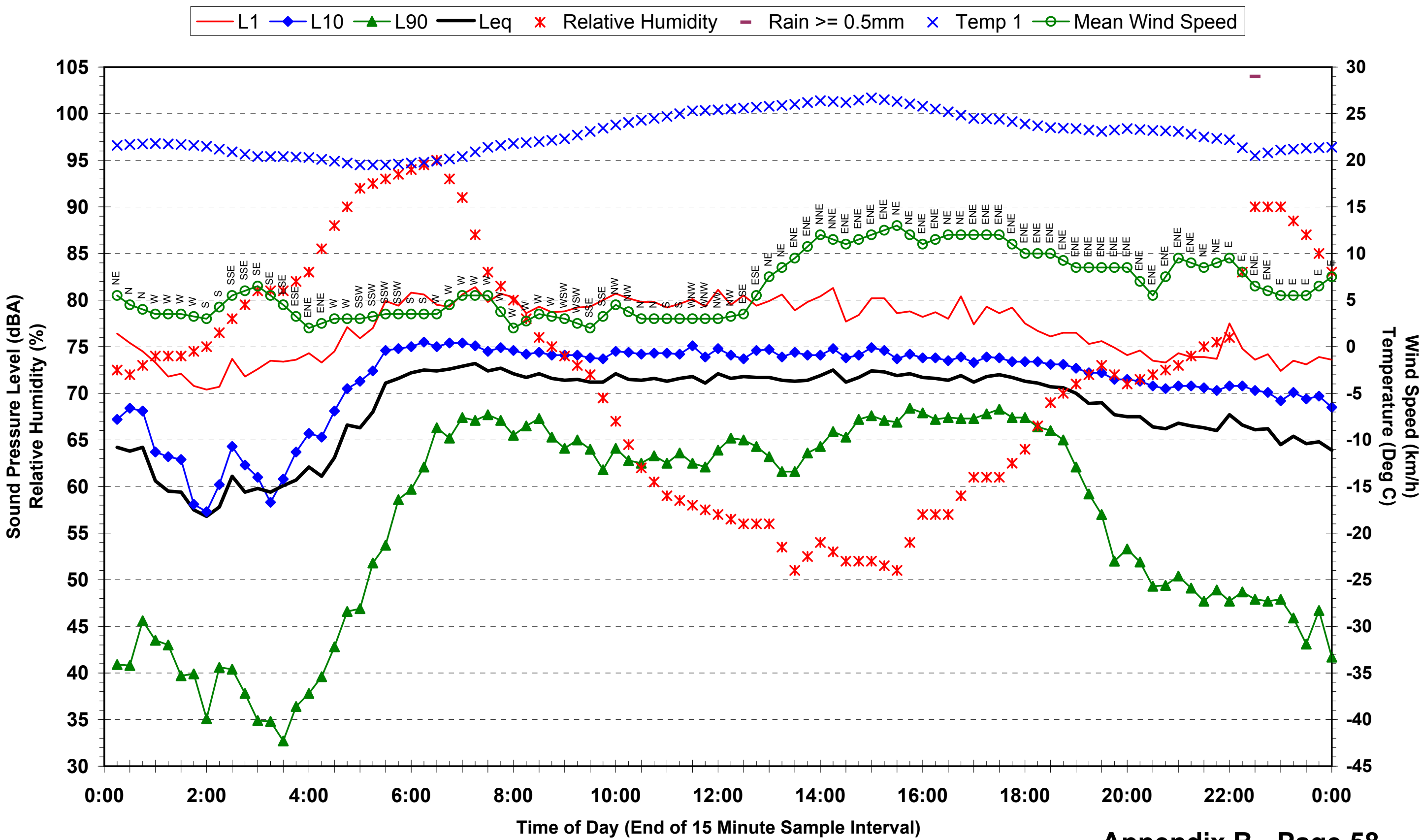
Appendix B - Page 56
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Thursday 22 November 2007



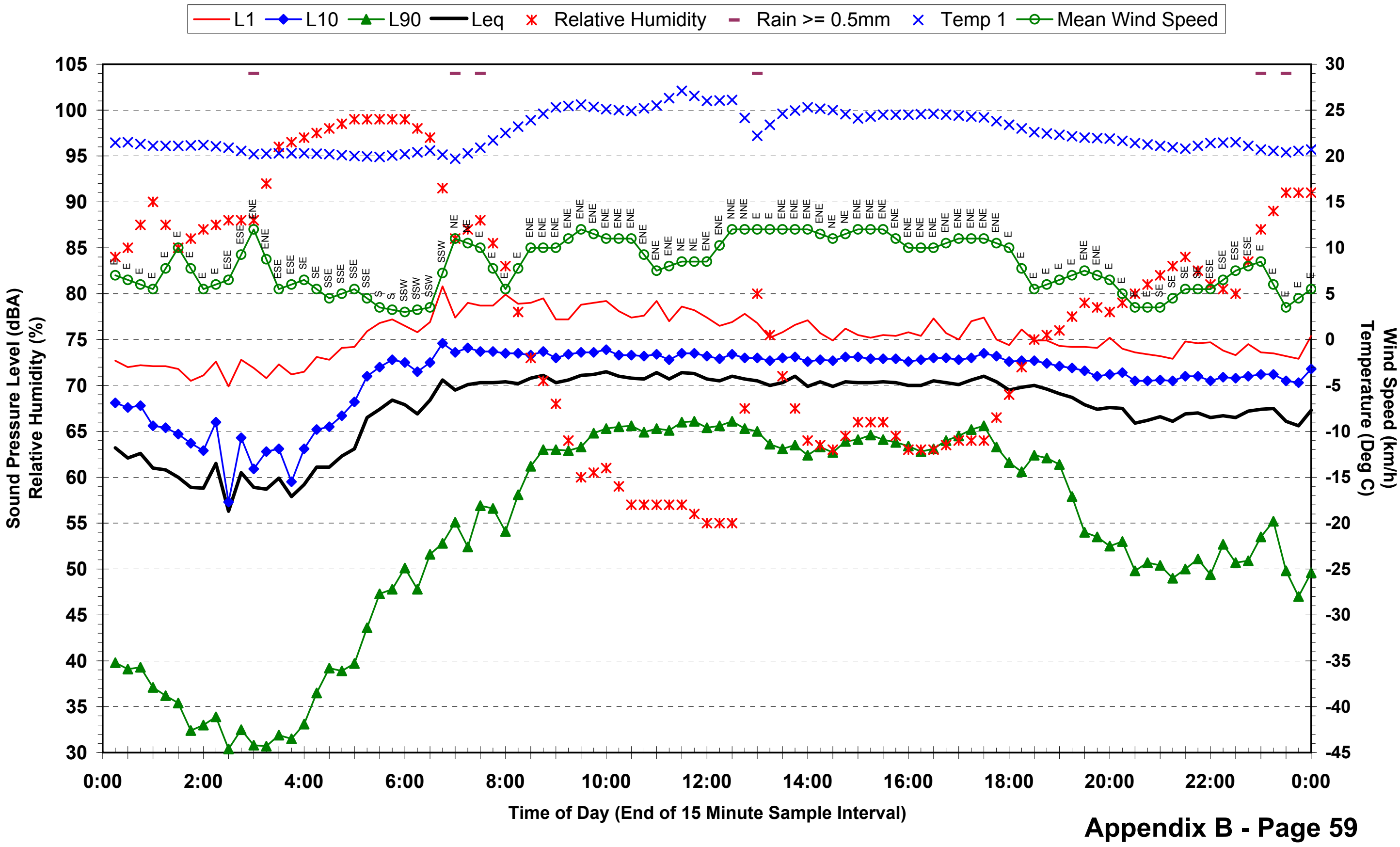
Appendix B - Page 57
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Friday 23 November 2007



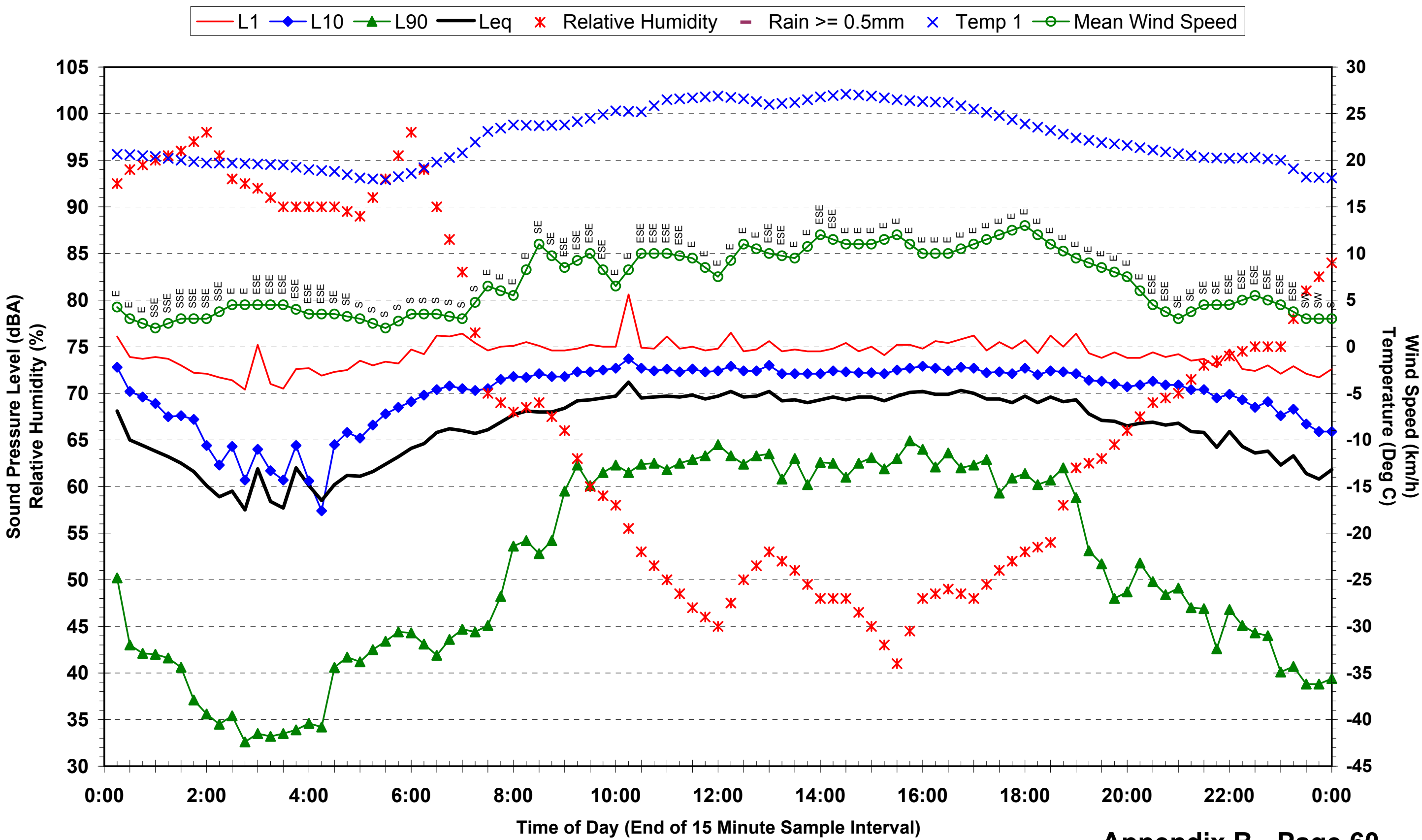
Appendix B - Page 58
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Saturday 24 November 2007



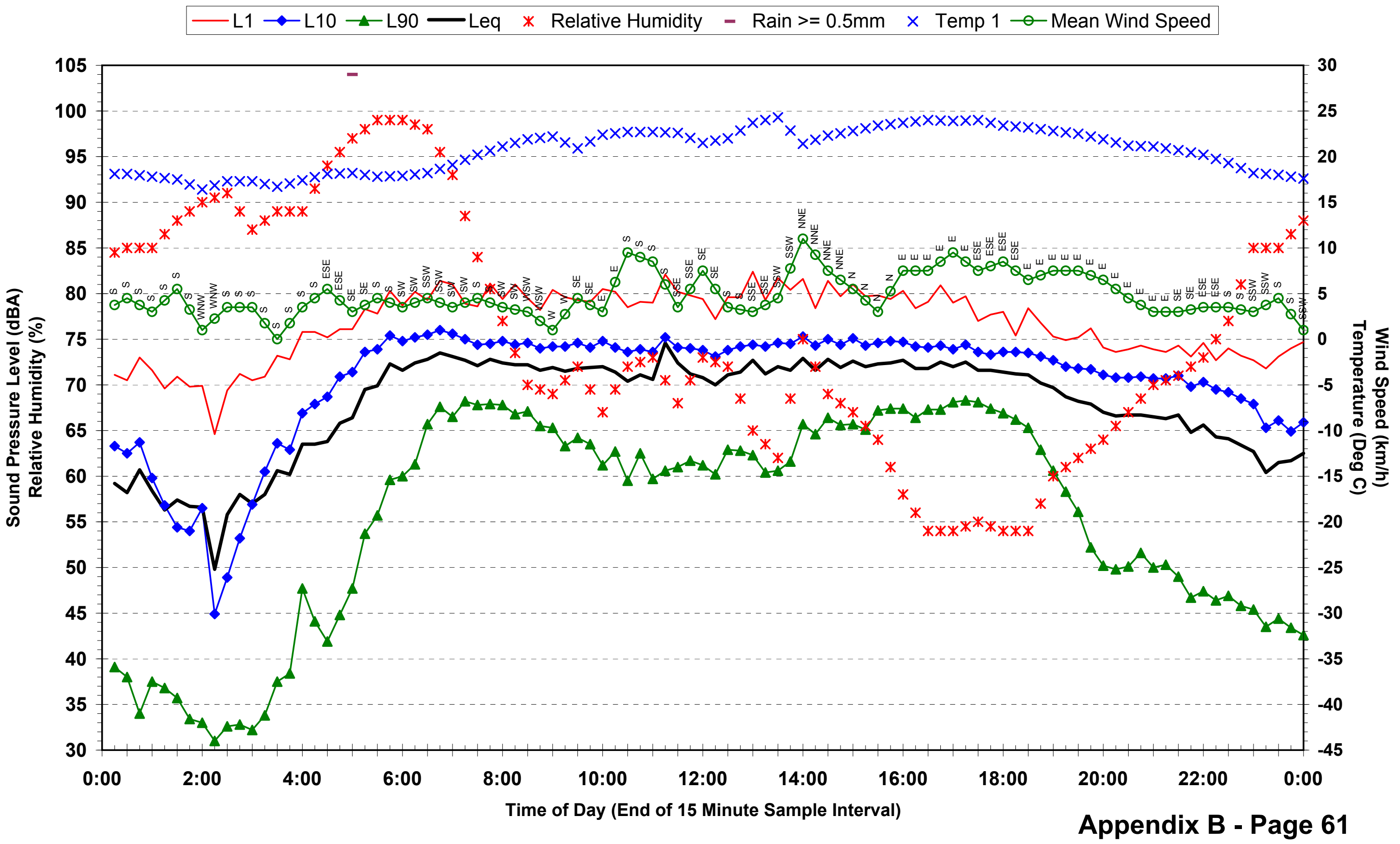
Appendix B - Page 59
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Sunday 25 November 2007



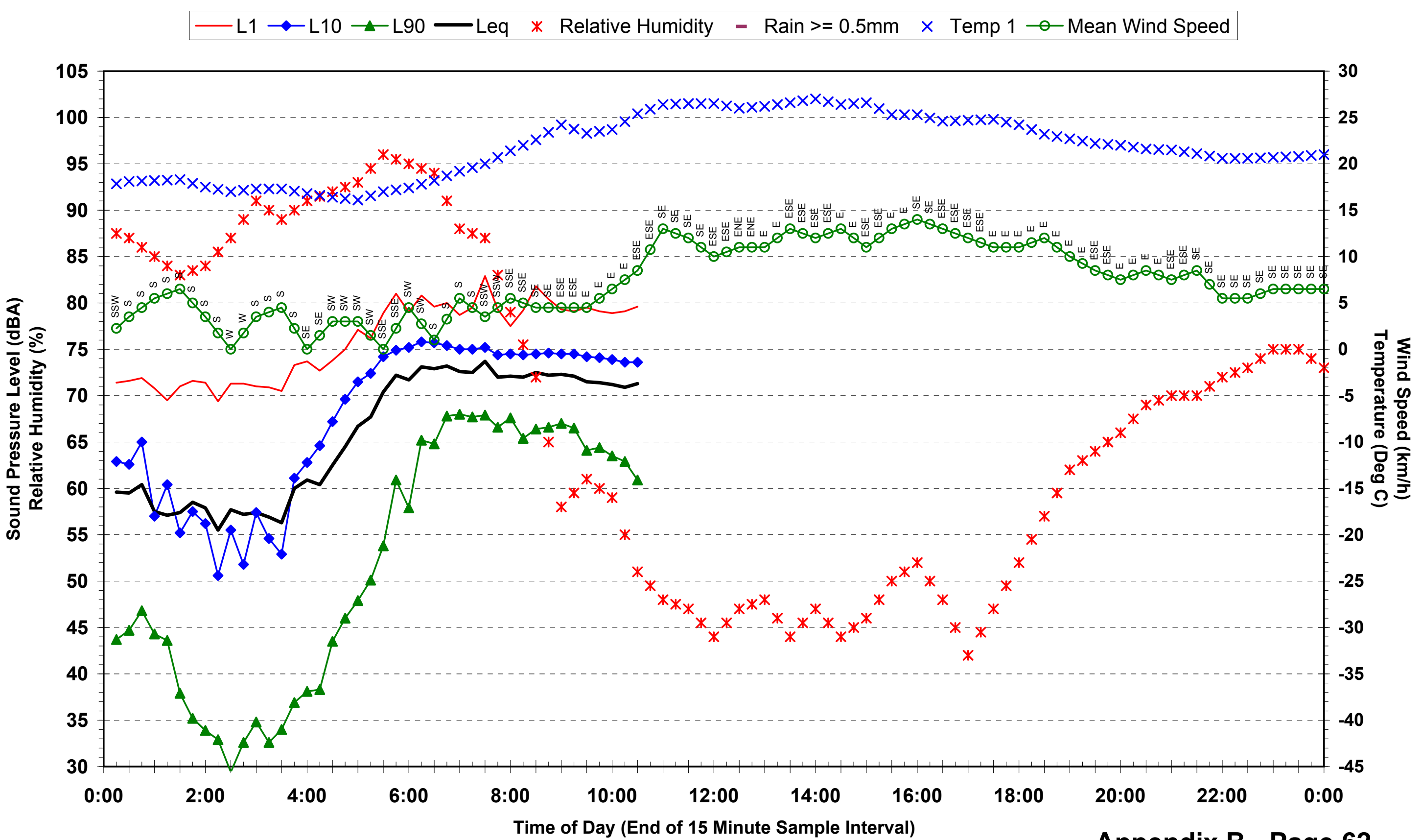
Appendix B - Page 60
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Monday 26 November 2007



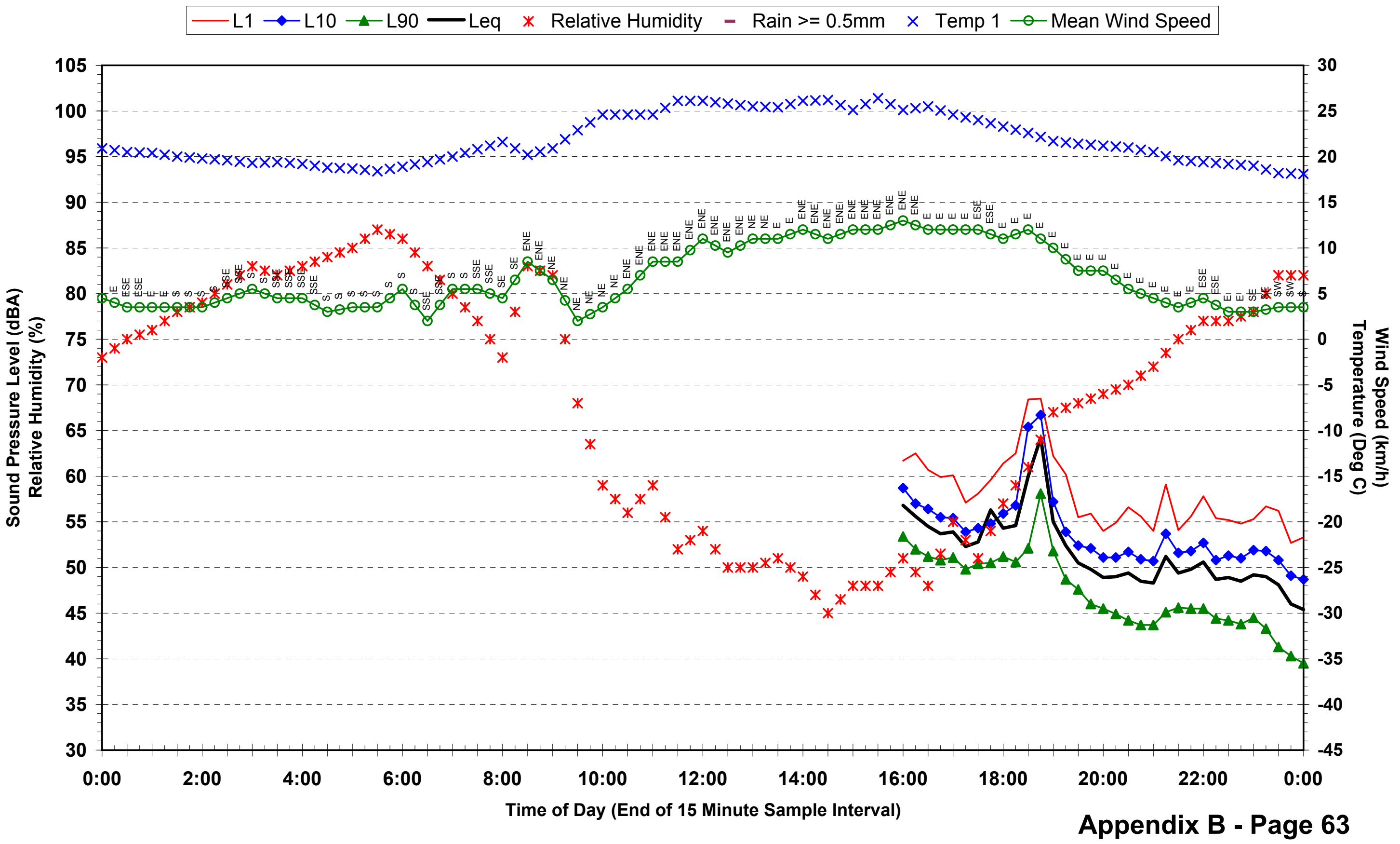
Appendix B - Page 61
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 6 - 69 Frederick Street, Toowong - Tuesday 27 November 2007

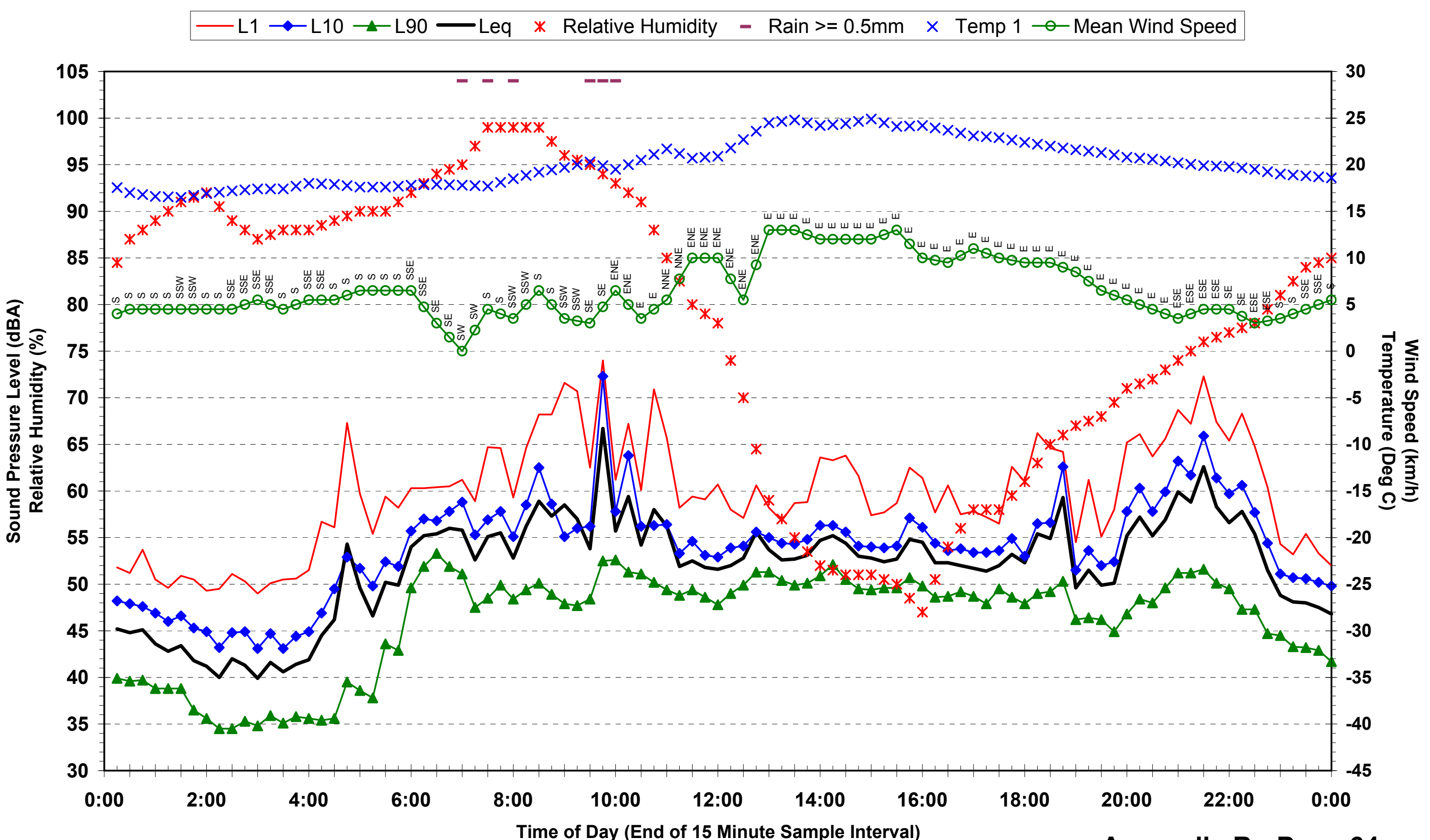


Appendix B - Page 62
Ambient Conditions
Heggies Report 20-1854

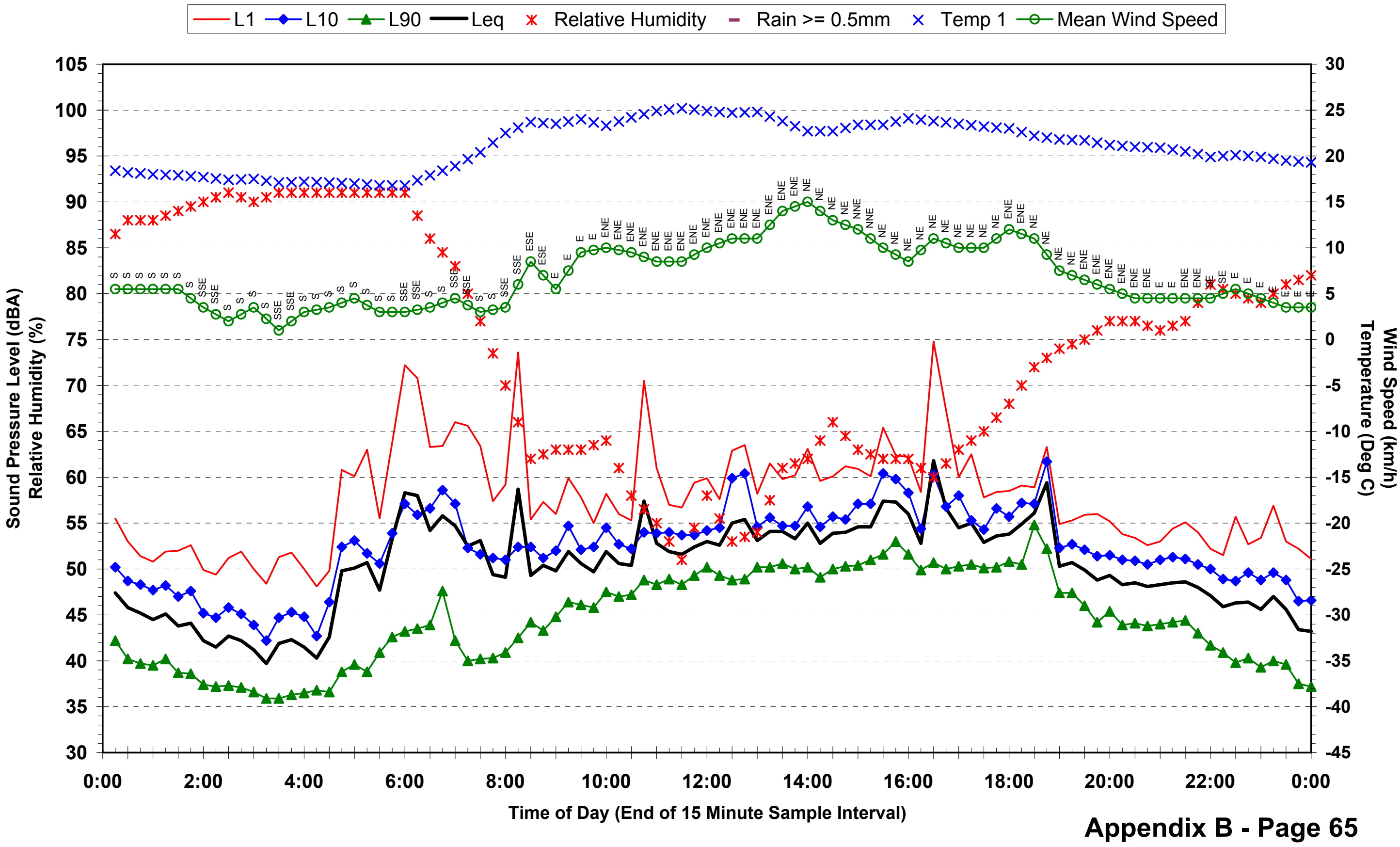
Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Friday 16 November 2007



Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Saturday 17 November 2007



Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Sunday 18 November 2007

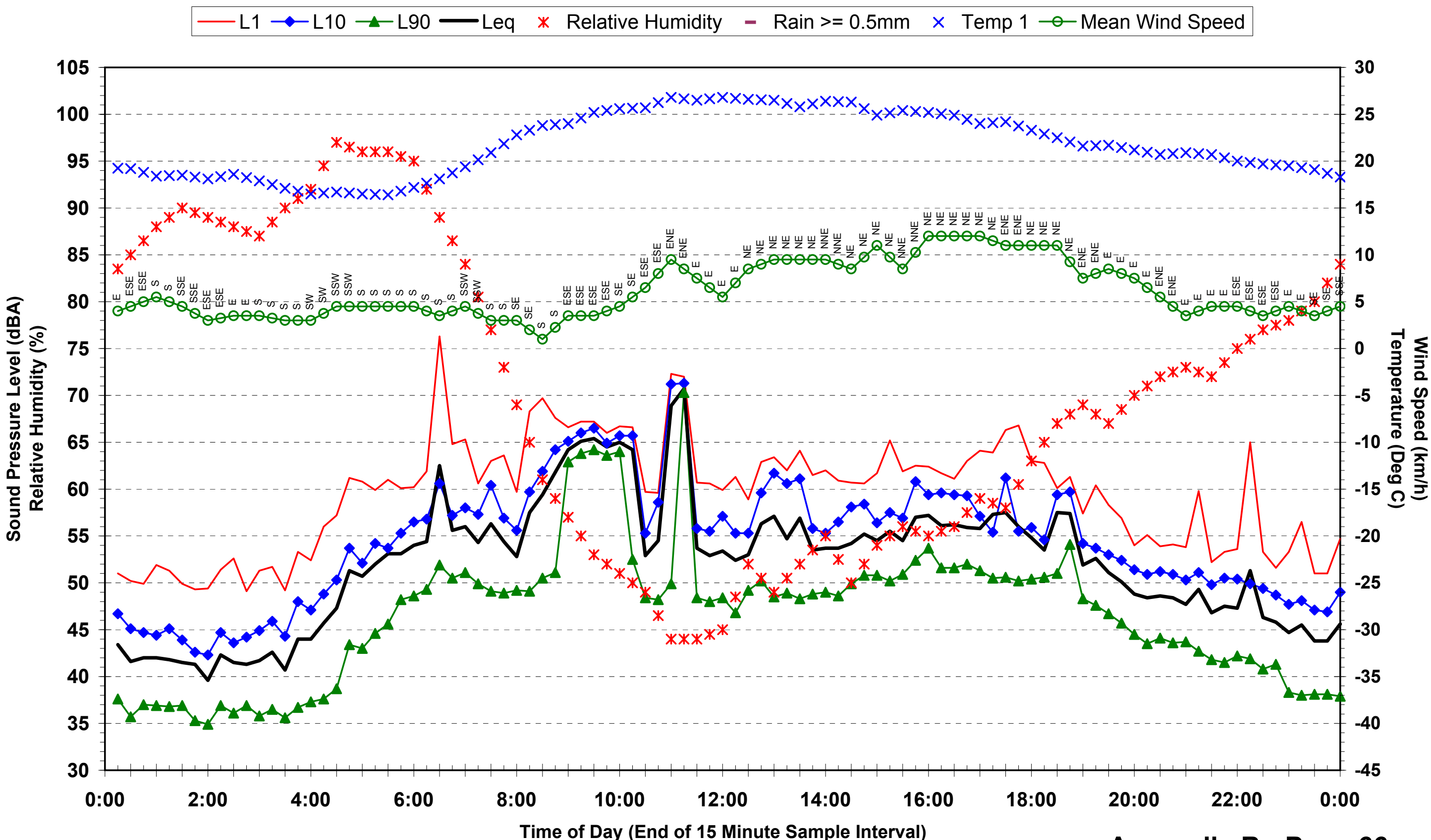


Appendix B - Page 65

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Monday 19 November 2007

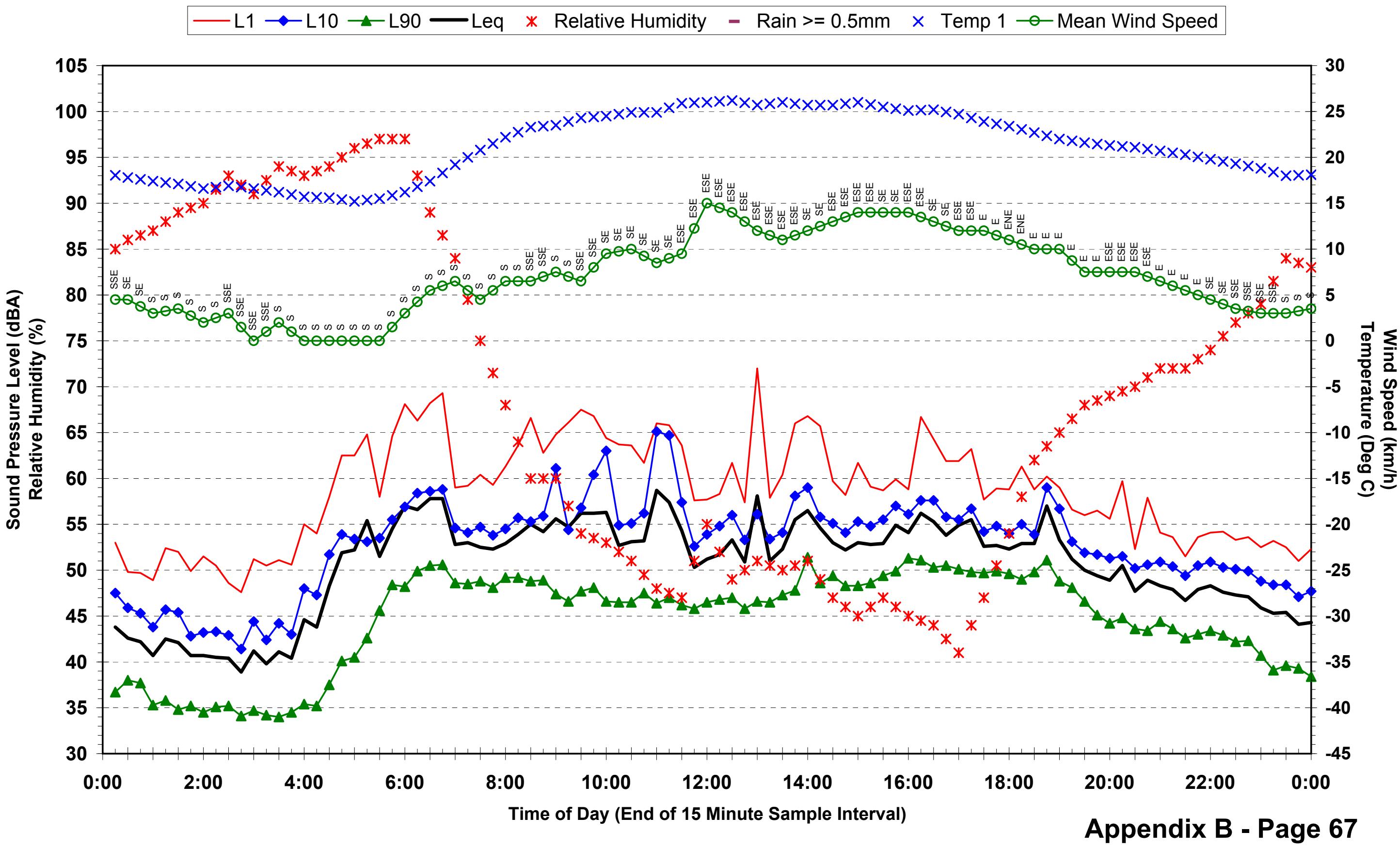


Appendix B - Page 66

Ambient Conditions

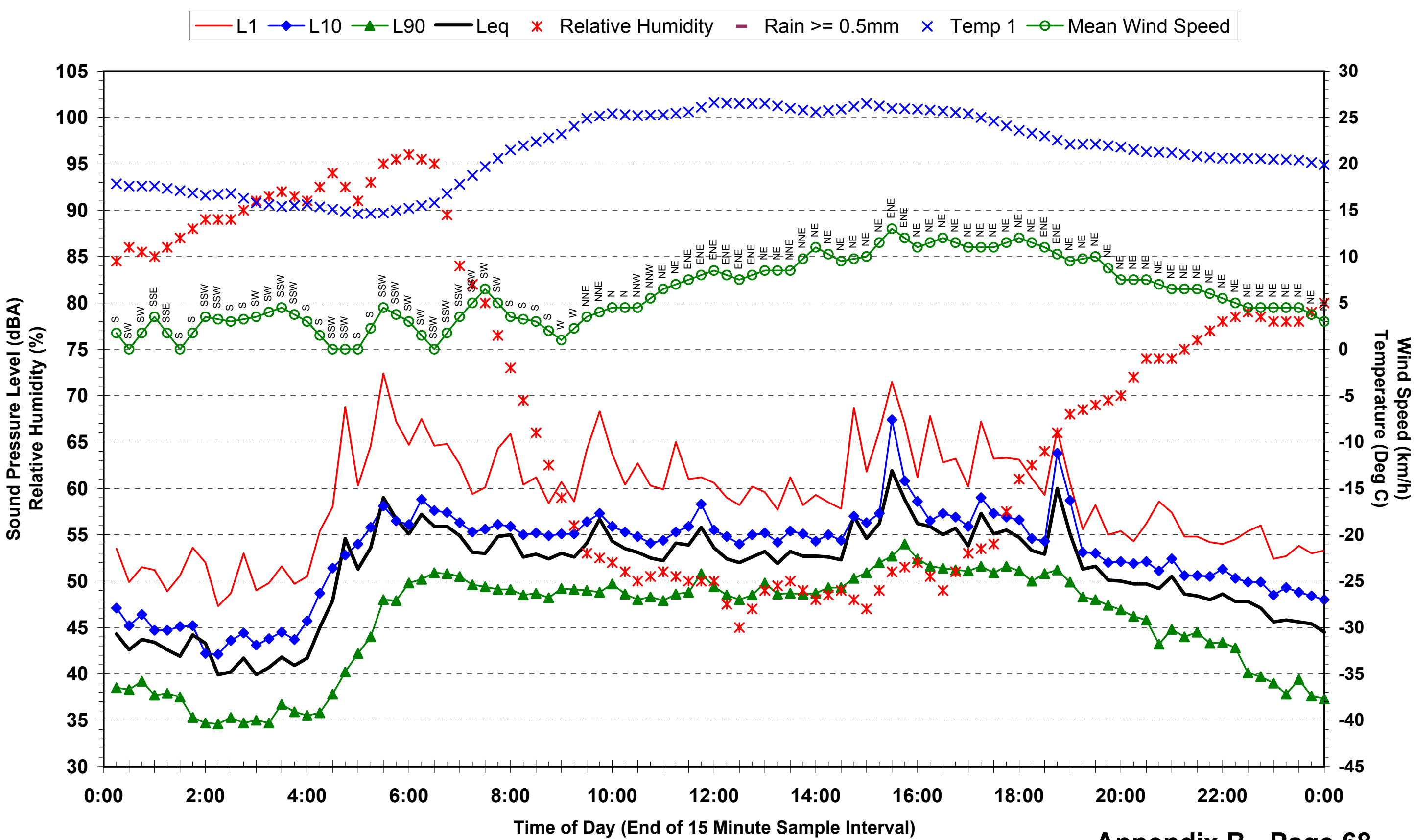
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Tuesday 20 November 2007

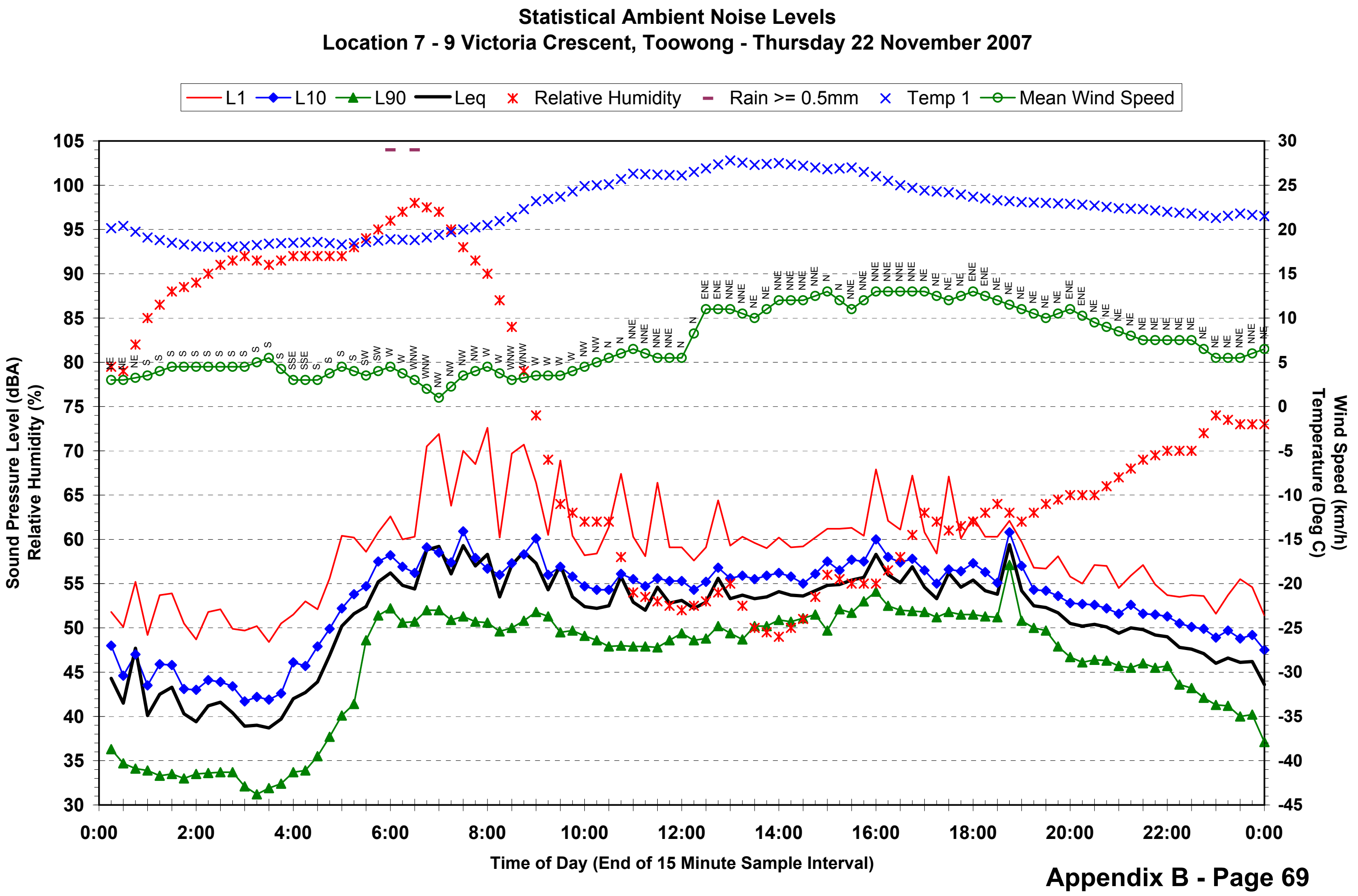


Appendix B - Page 67
Ambient Conditions
Heggies Report 20-1854

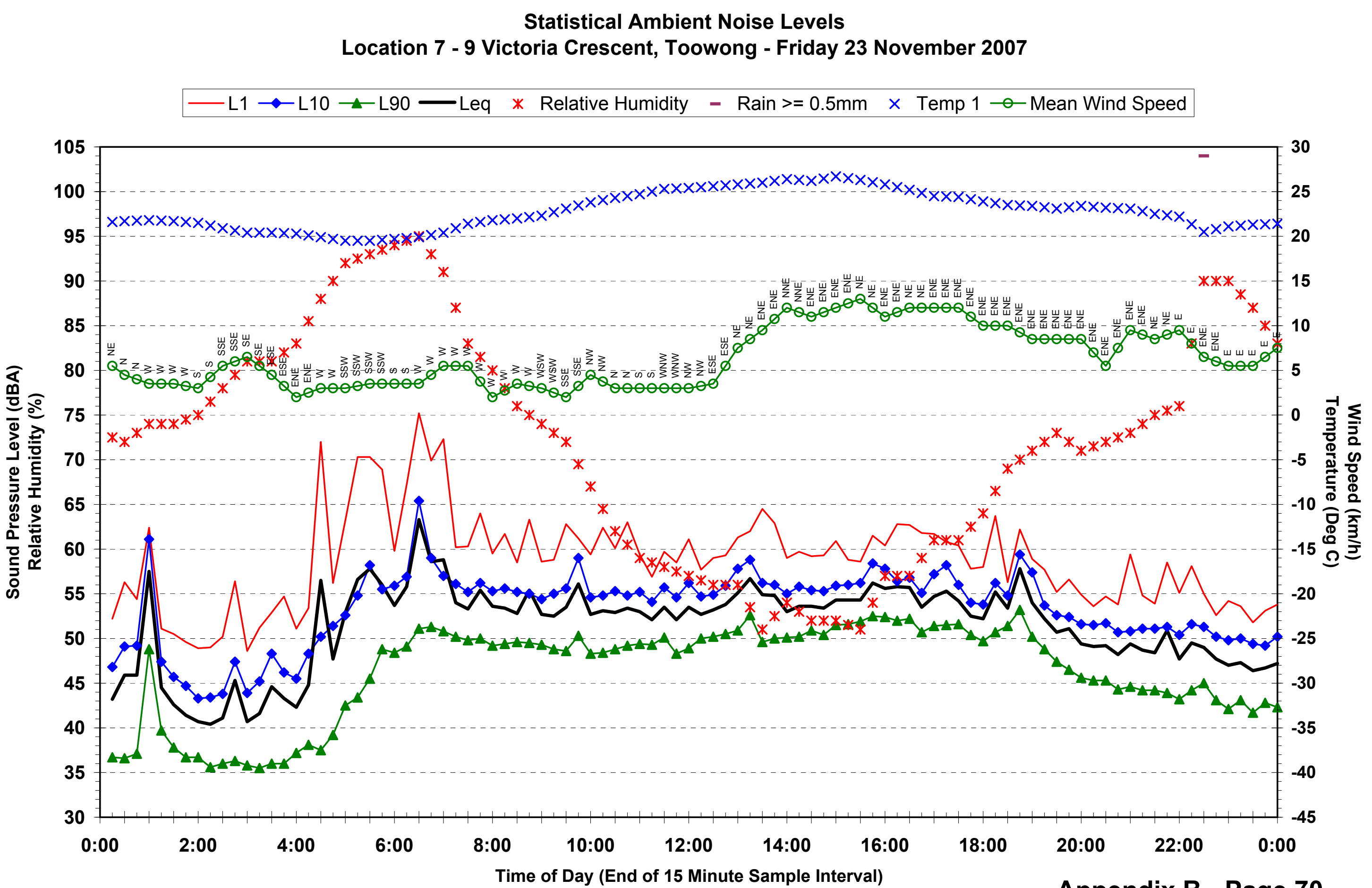
Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Wednesday 21 November 2007



Appendix B - Page 68
Ambient Conditions
Heggies Report 20-1854

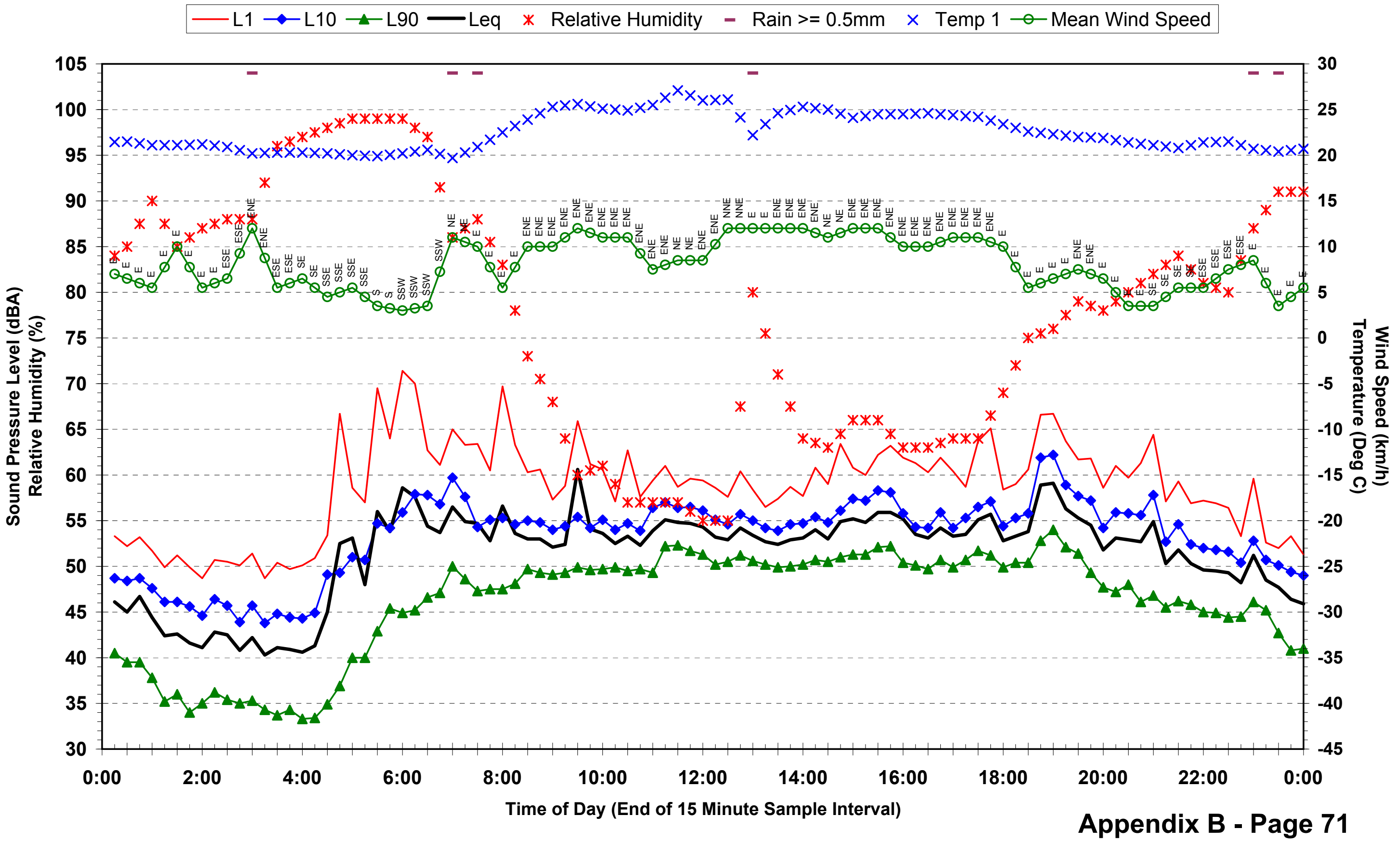


Appendix B - Page 69
Ambient Conditions
Heggies Report 20-1854



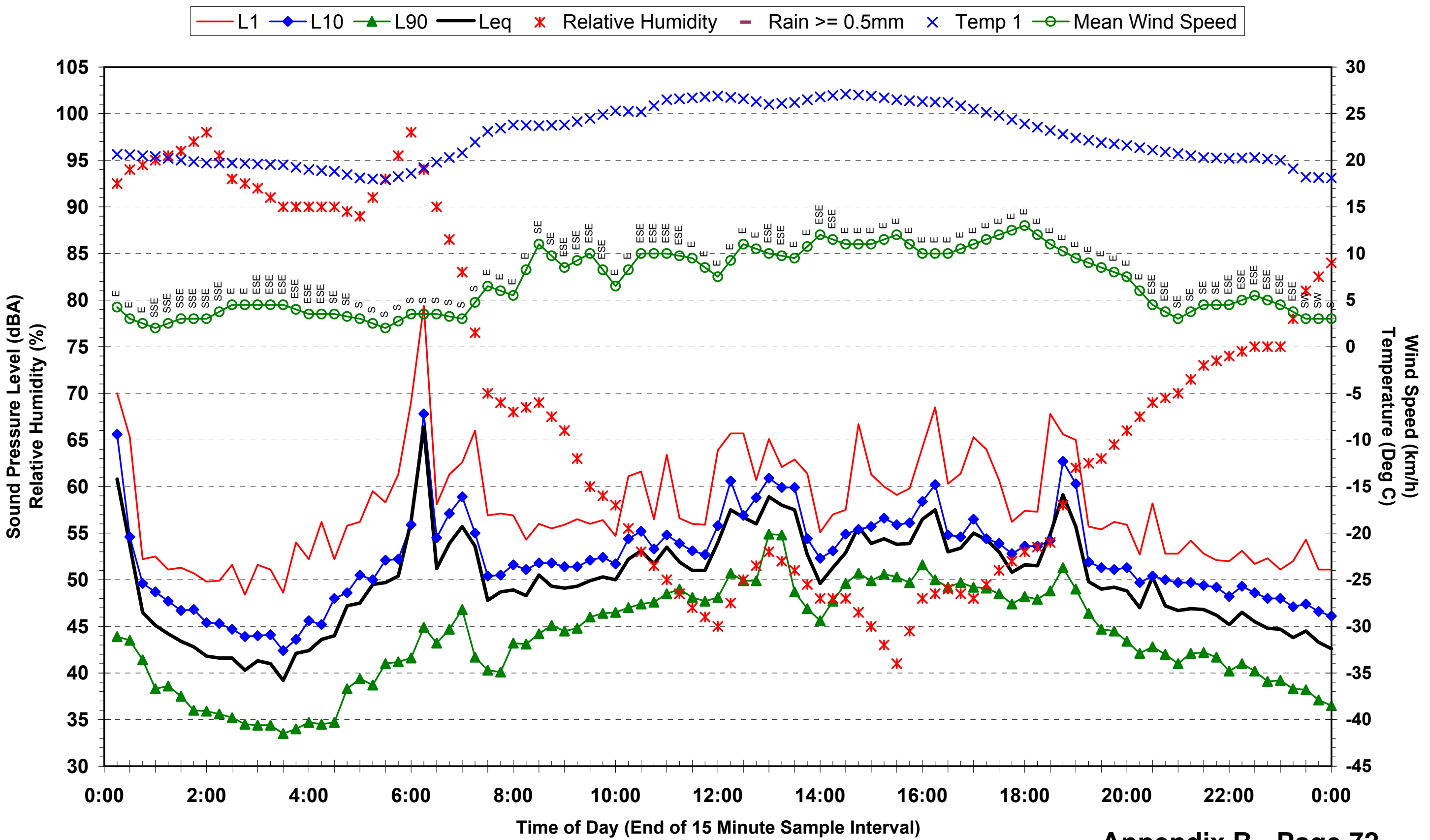
Appendix B - Page 70
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Saturday 24 November 2007

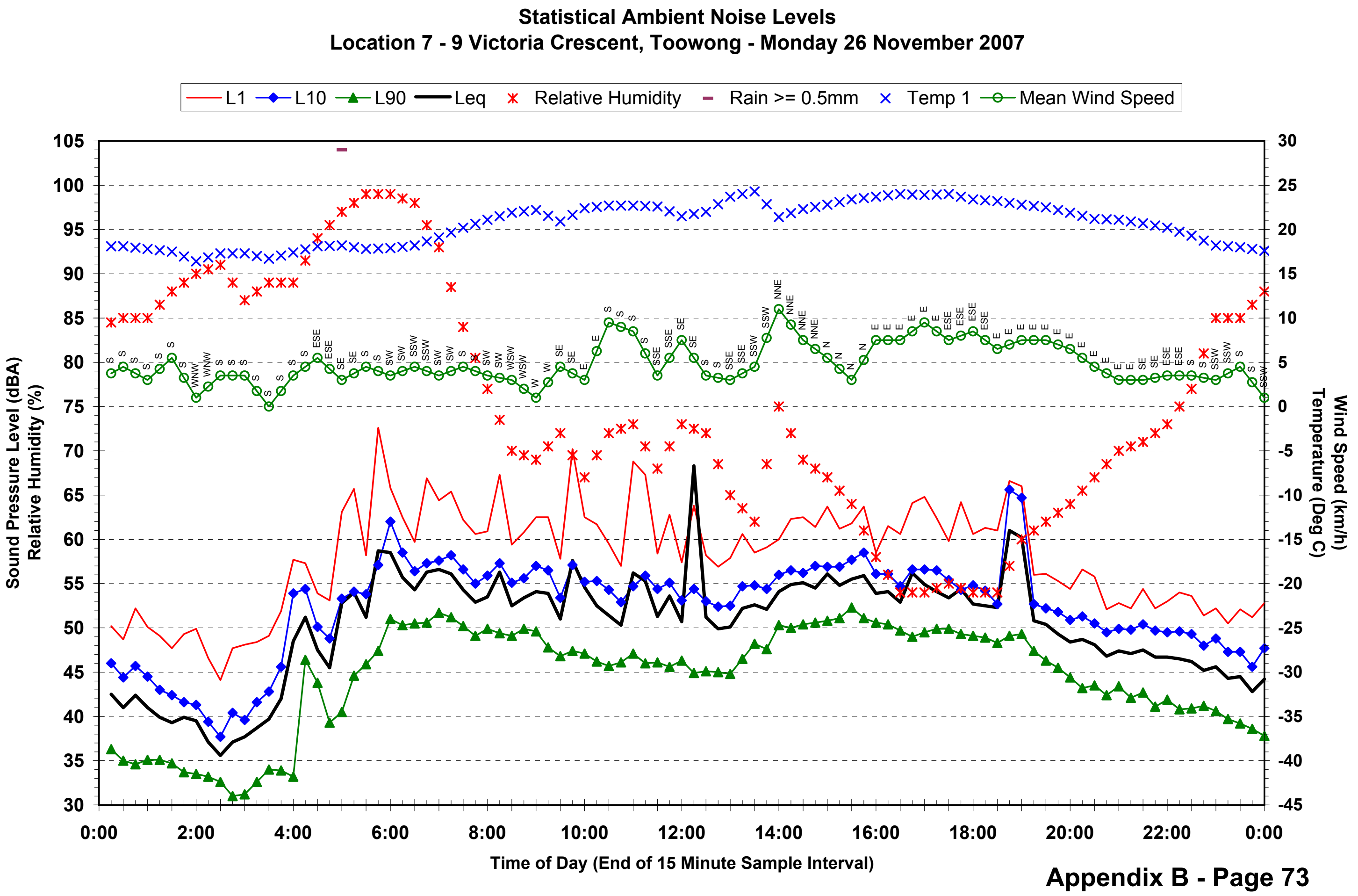


Appendix B - Page 71
Ambient Conditions
Heggies Report 20-1854

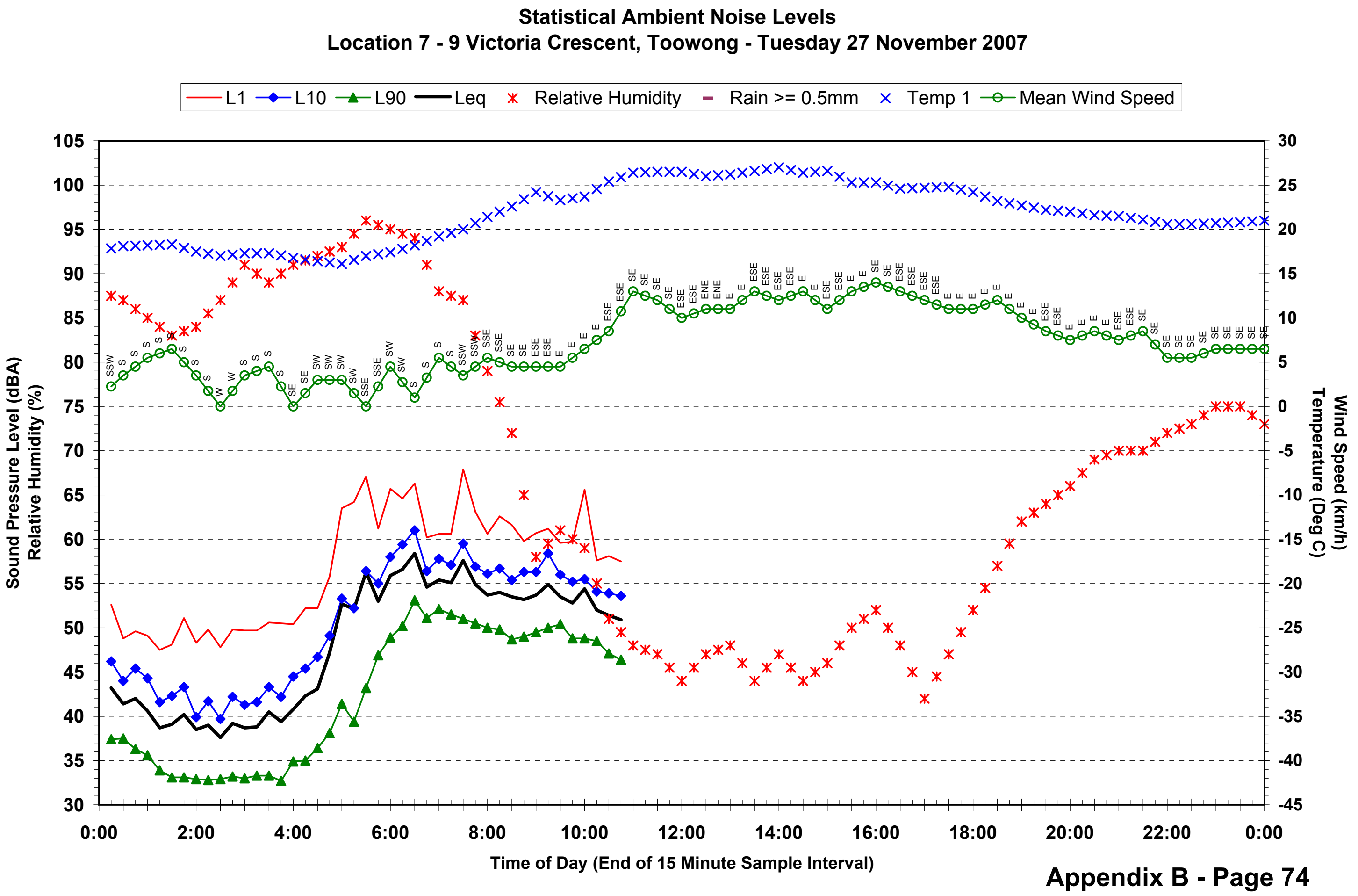
Statistical Ambient Noise Levels
Location 7 - 9 Victoria Crescent, Toowong - Sunday 25 November 2007



Appendix B - Page 72
Ambient Conditions
Heggies Report 20-1854

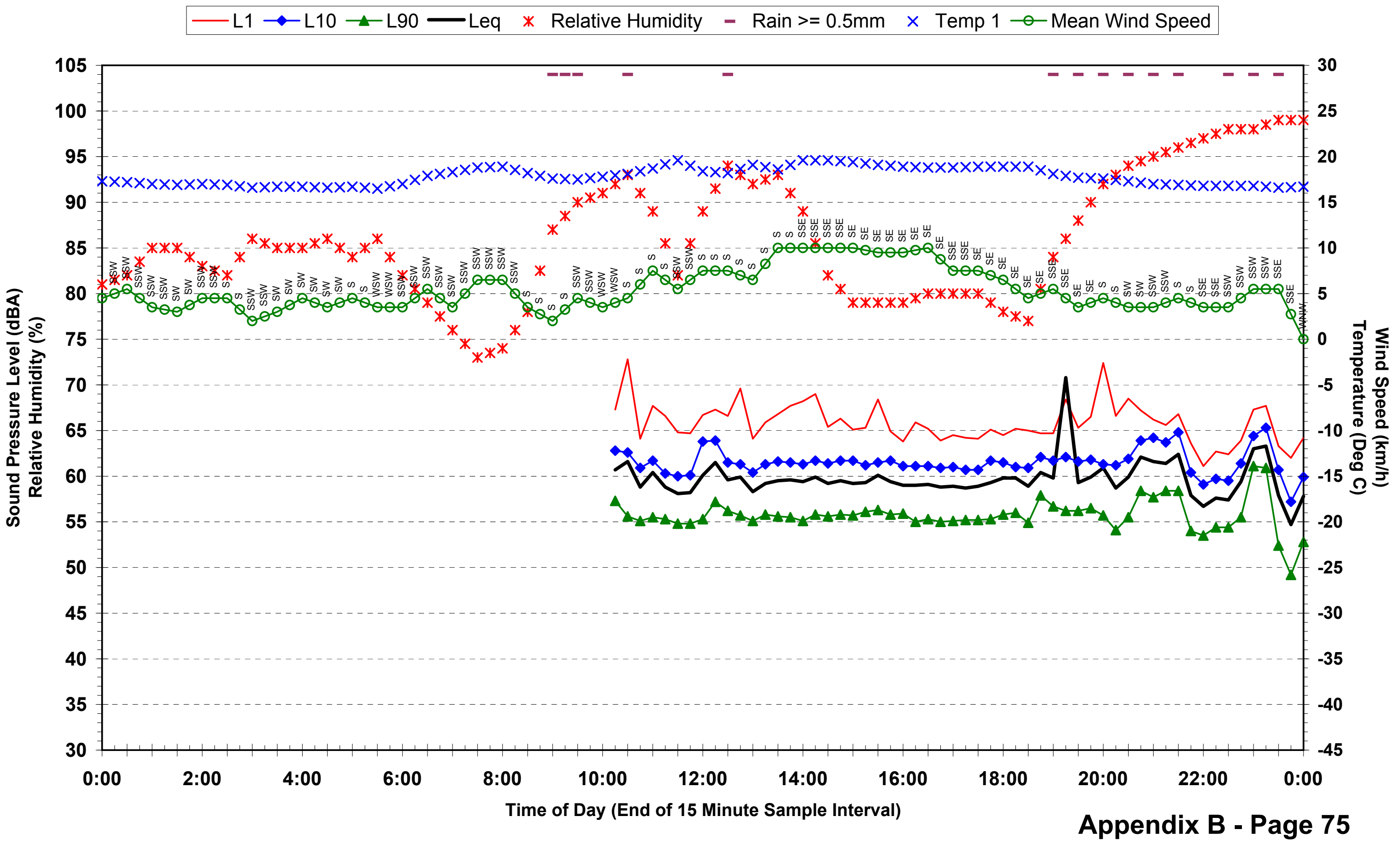


Appendix B - Page 73
Ambient Conditions
Heggies Report 20-1854



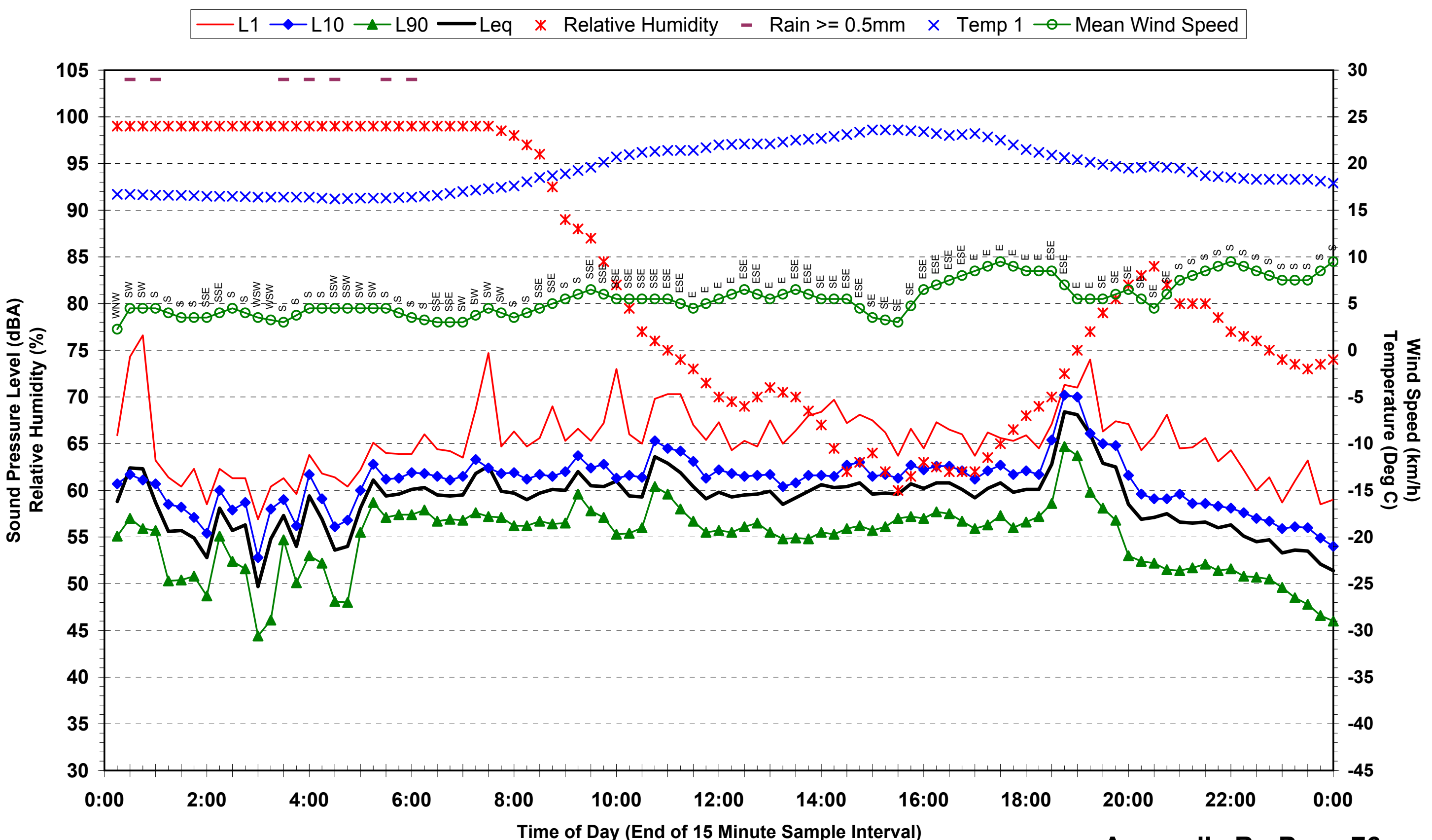
Appendix B - Page 74
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Wednesday 7 November 2007



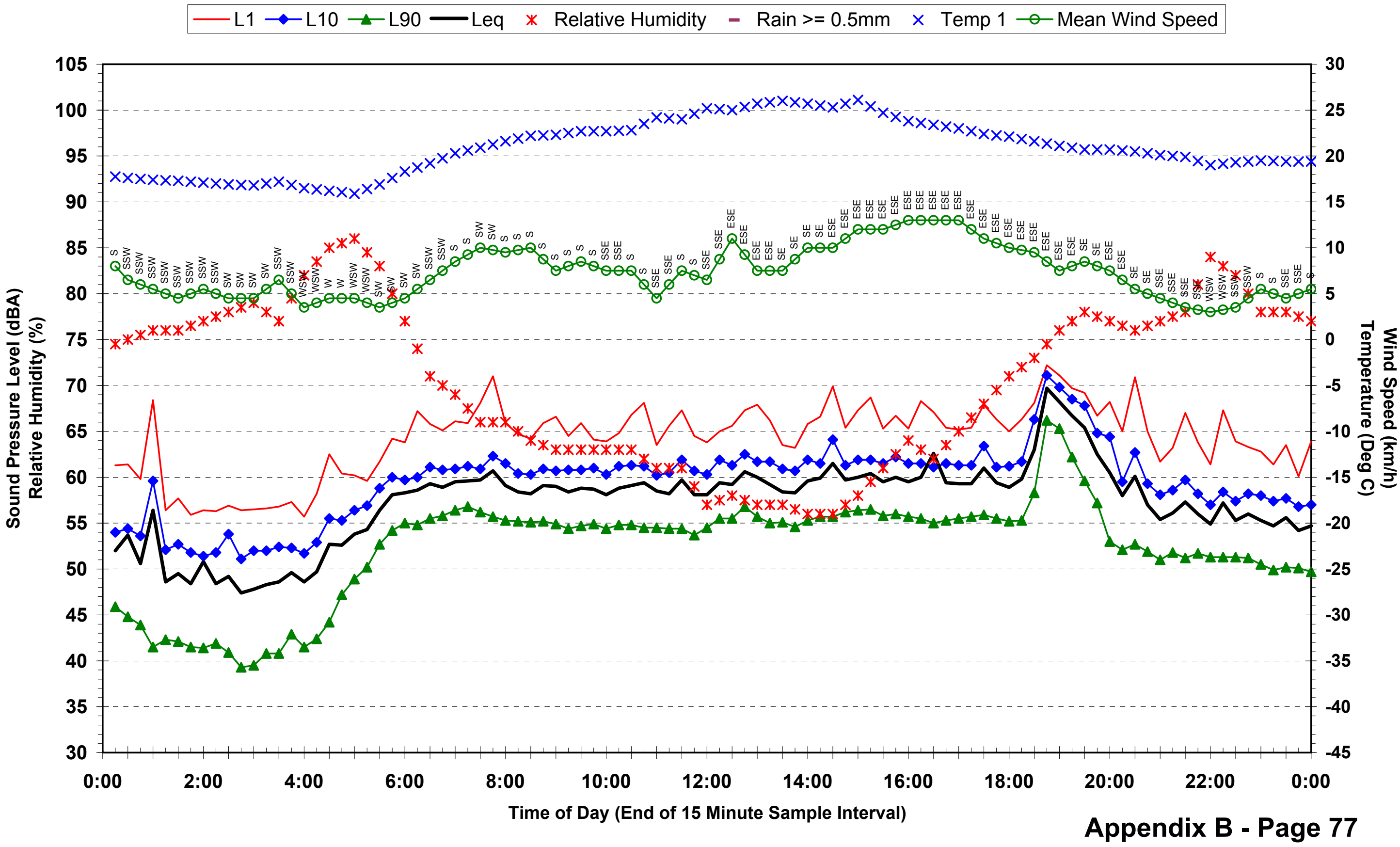
Appendix B - Page 75
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Thursday 8 November 2007



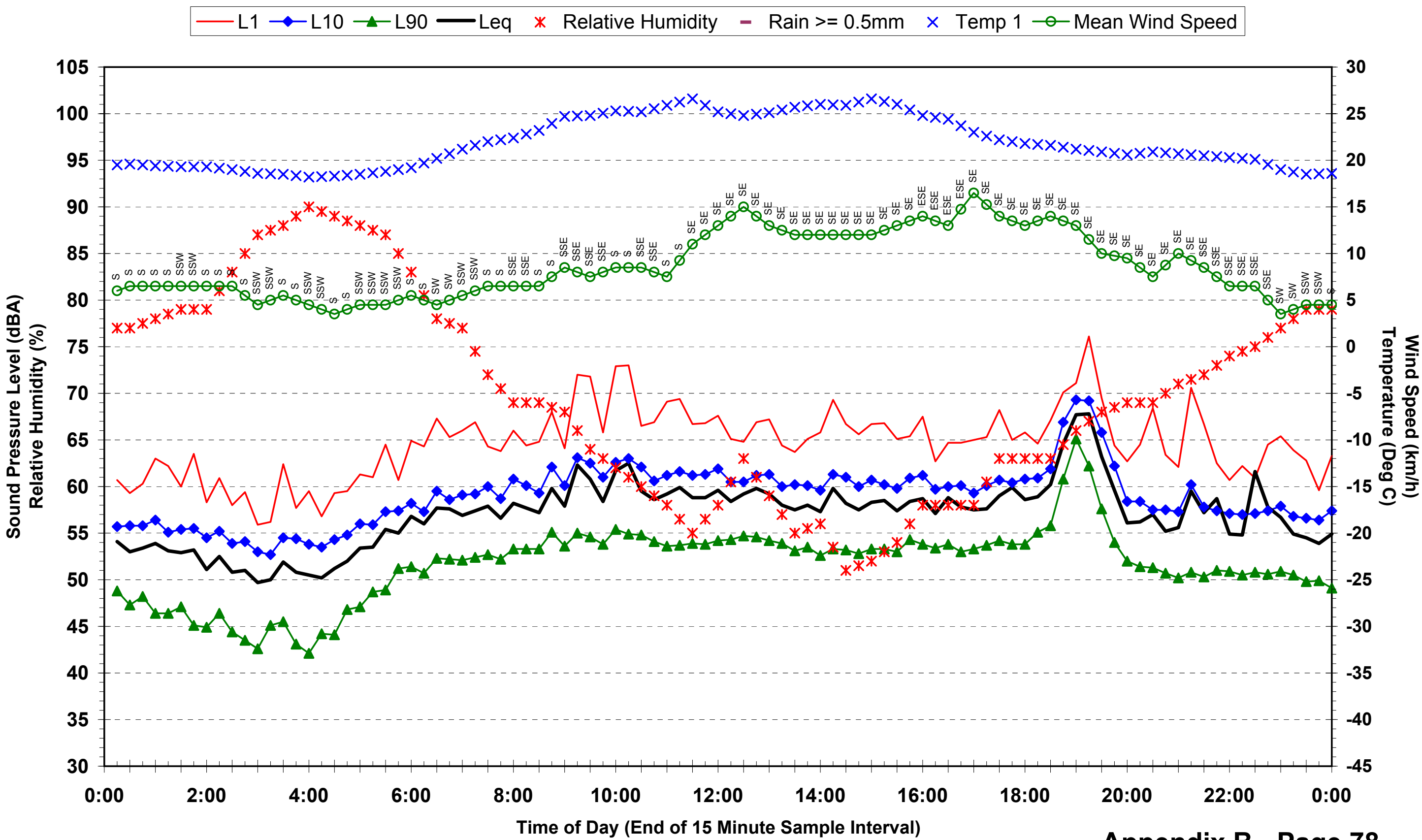
Appendix B - Page 76
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Friday 9 November 2007



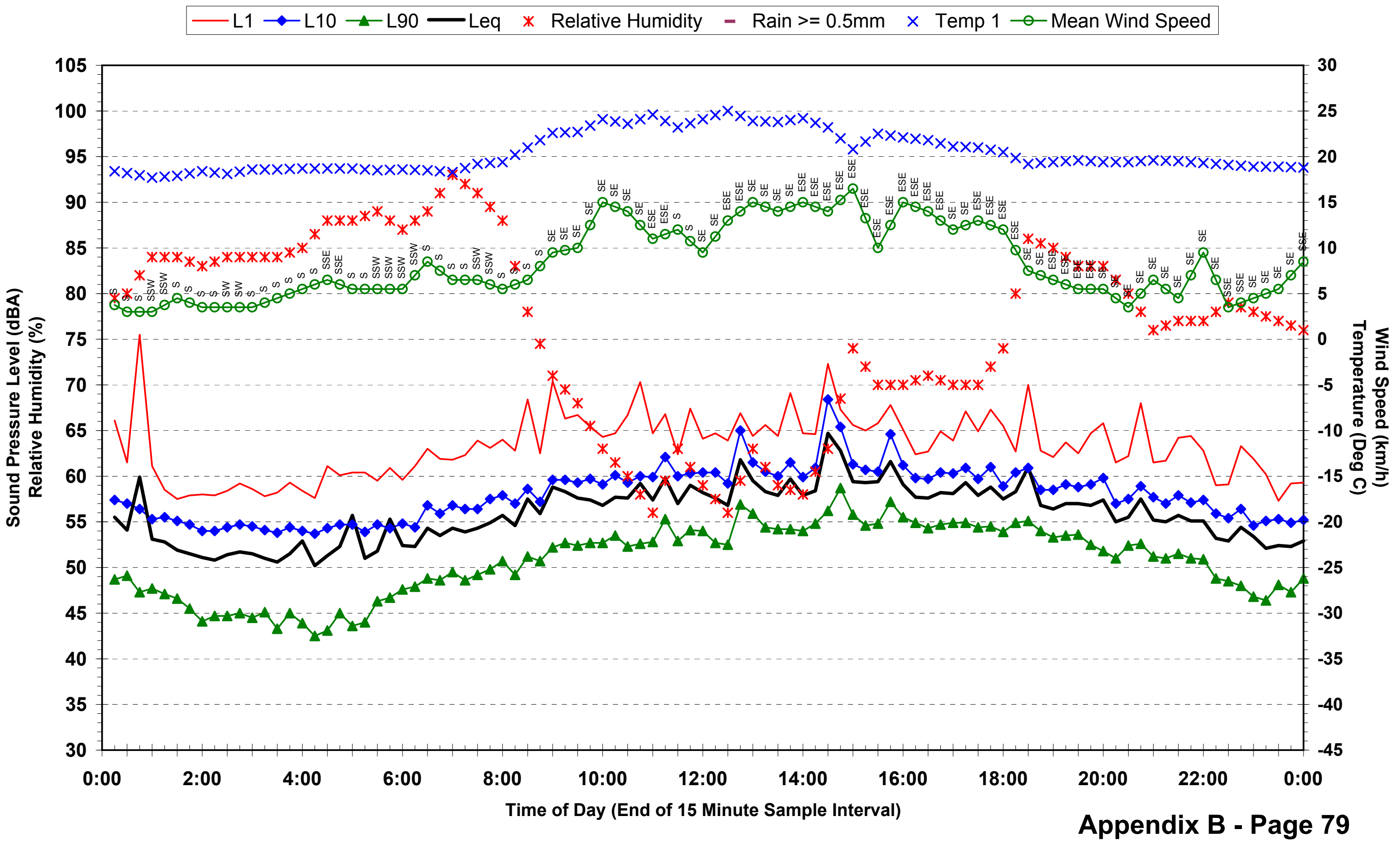
Appendix B - Page 77
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Saturday 10 November 2007



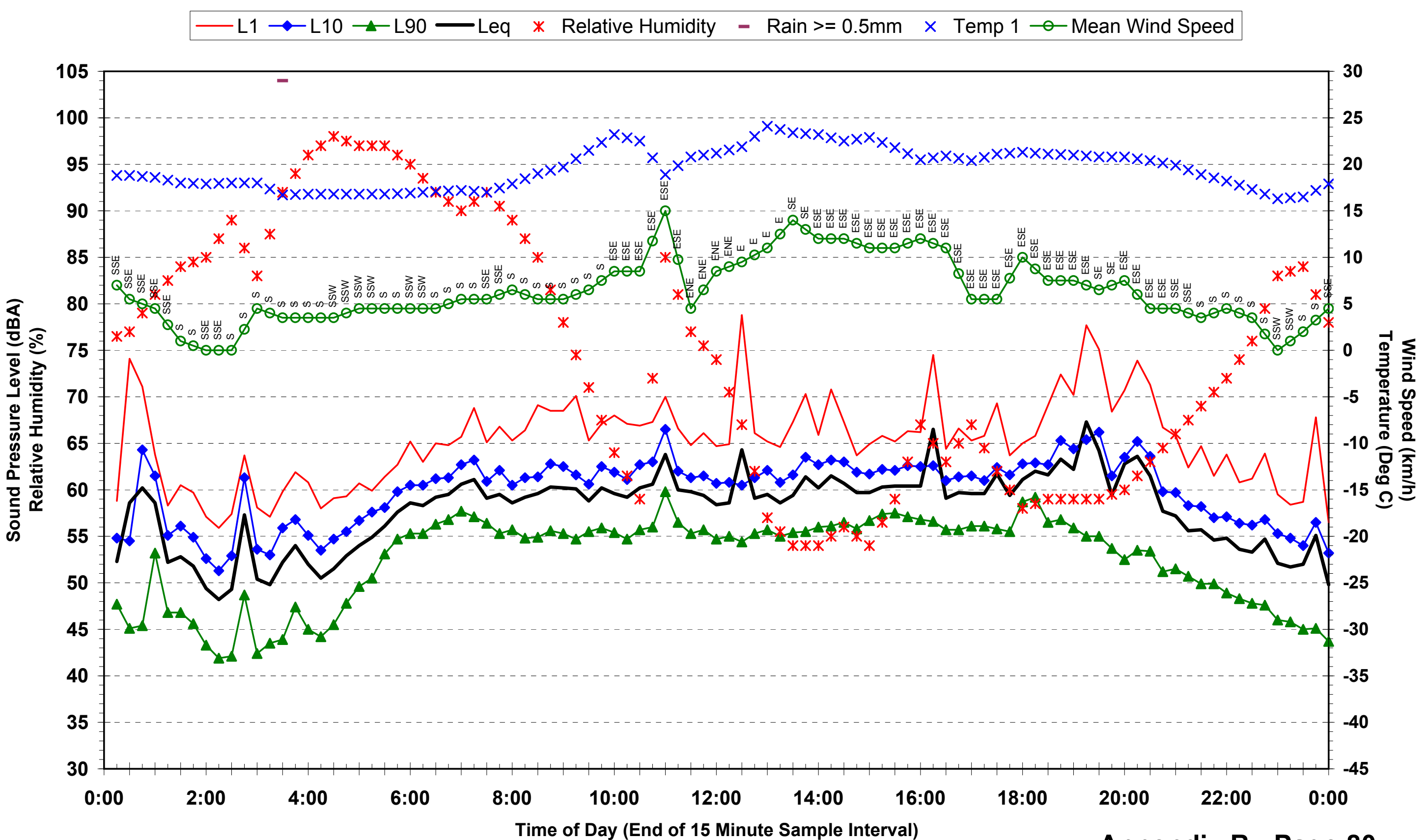
Appendix B - Page 78
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Sunday 11 November 2007



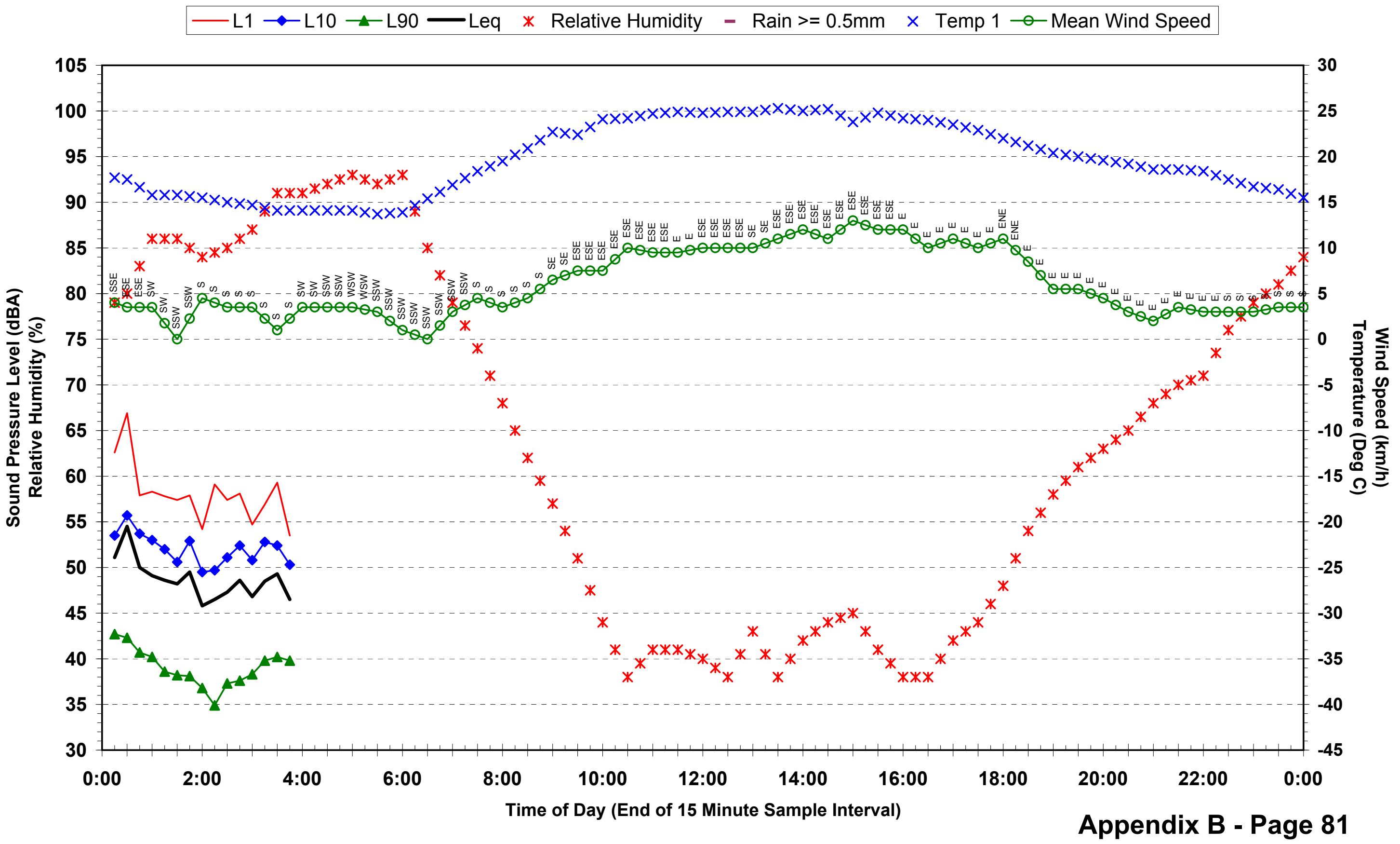
Appendix B - Page 79
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Monday 12 November 2007

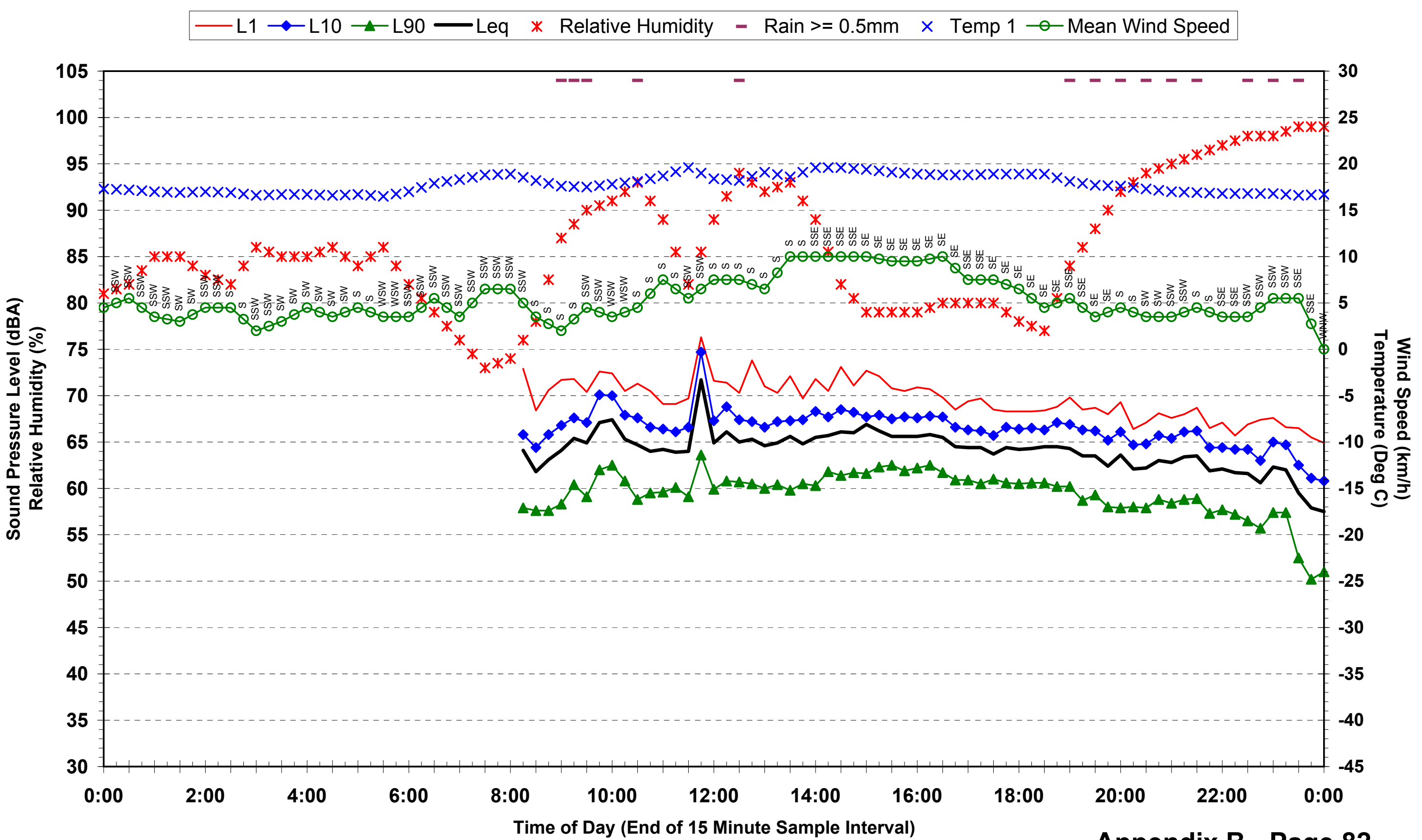


Appendix B - Page 80
Ambient Conditions
Heggies Report 20-1854

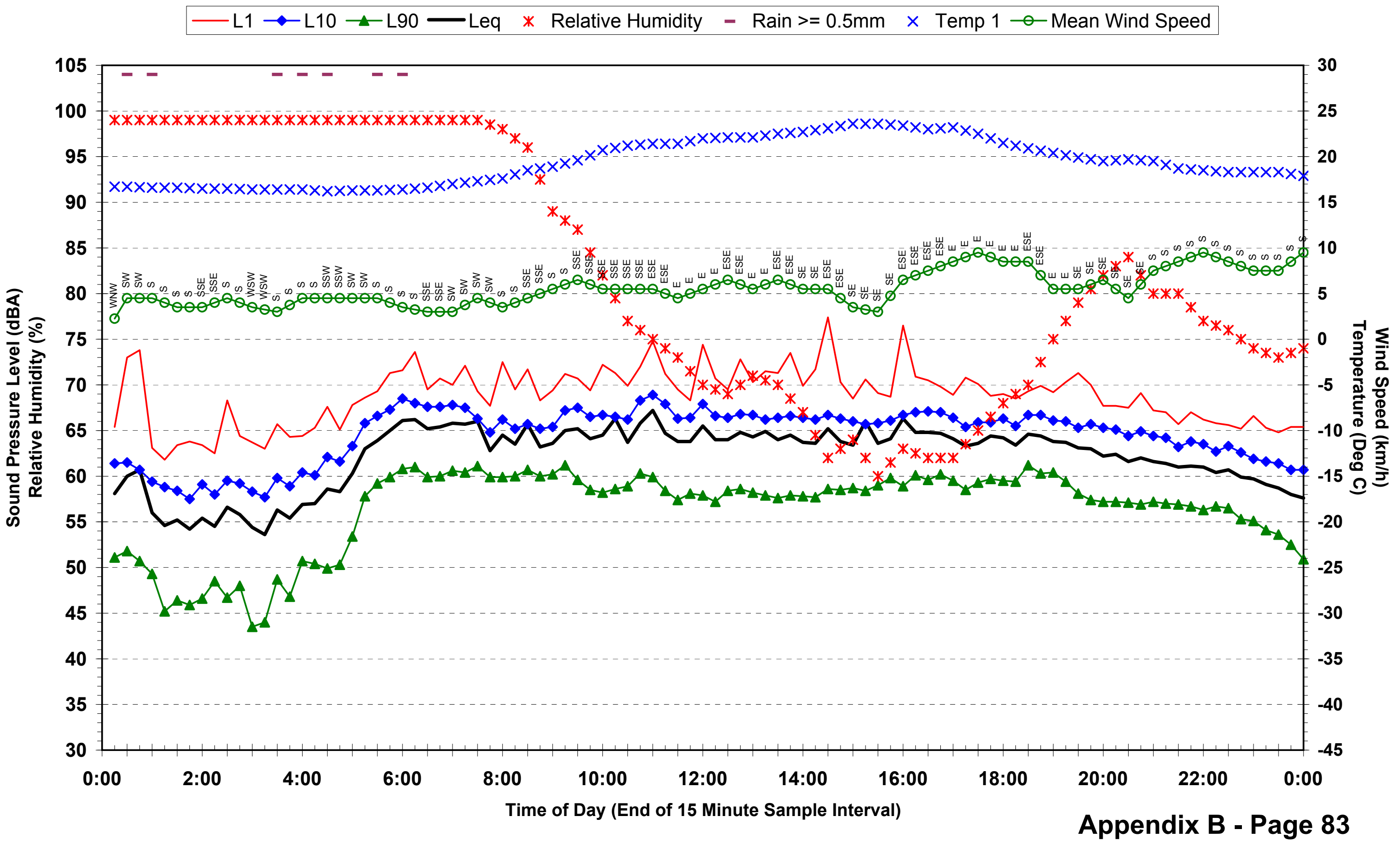
Statistical Ambient Noise Levels
Location 8 - 5 Clyde Street, Brisbane City - Tuesday 13 November 2007



Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Wednesday 7 November 2007

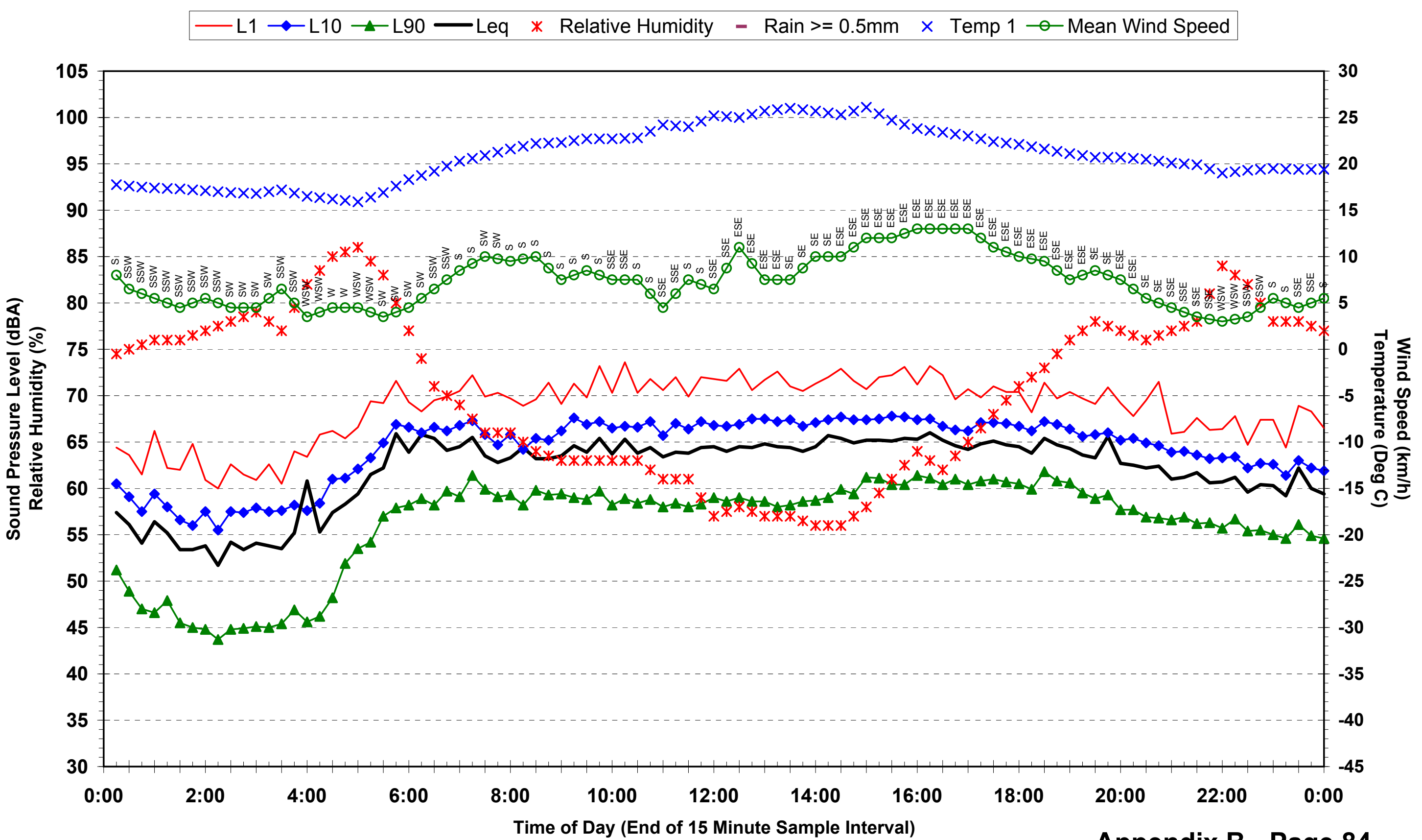


Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Thursday 8 November 2007



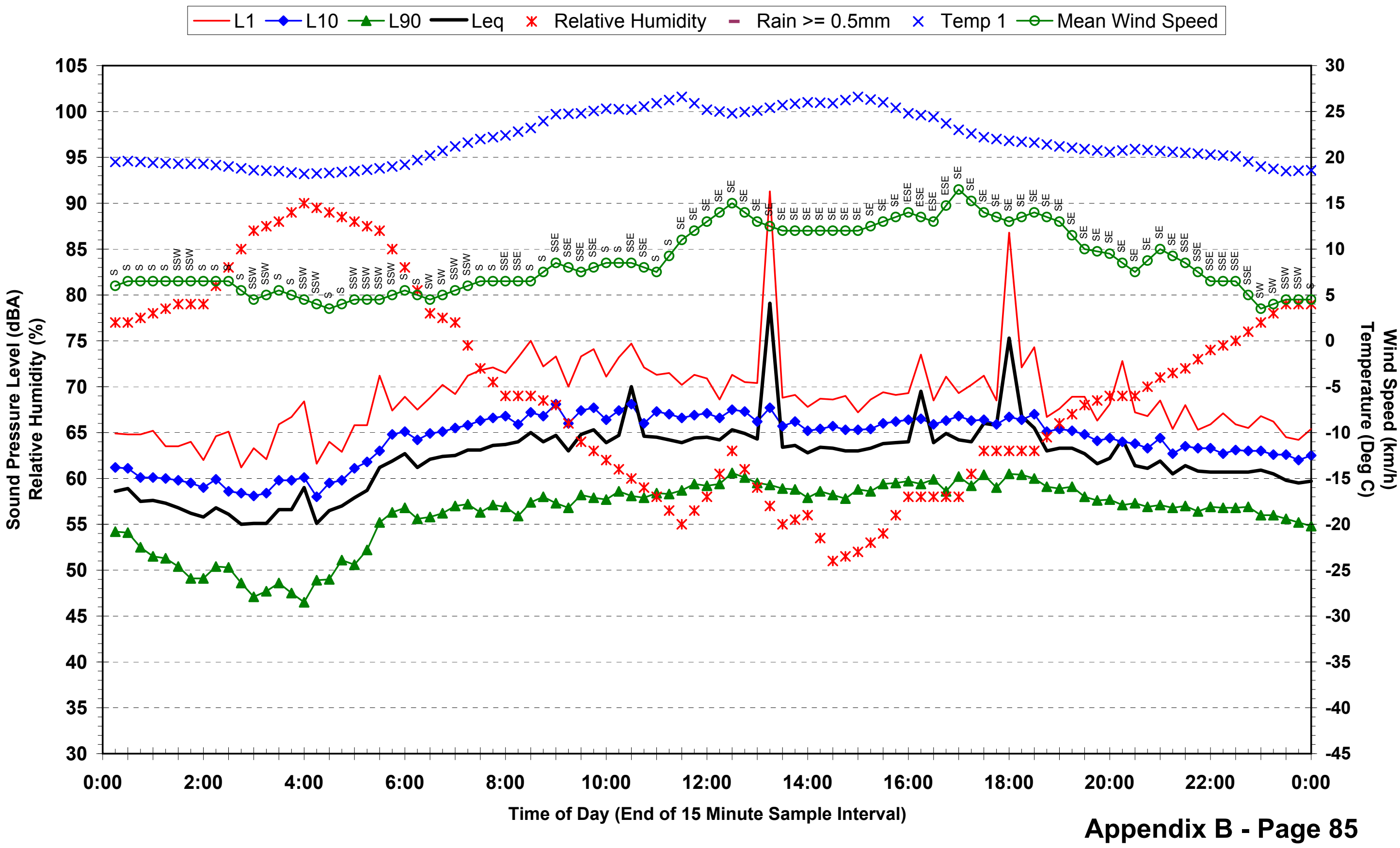
Appendix B - Page 83
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Friday 9 November 2007



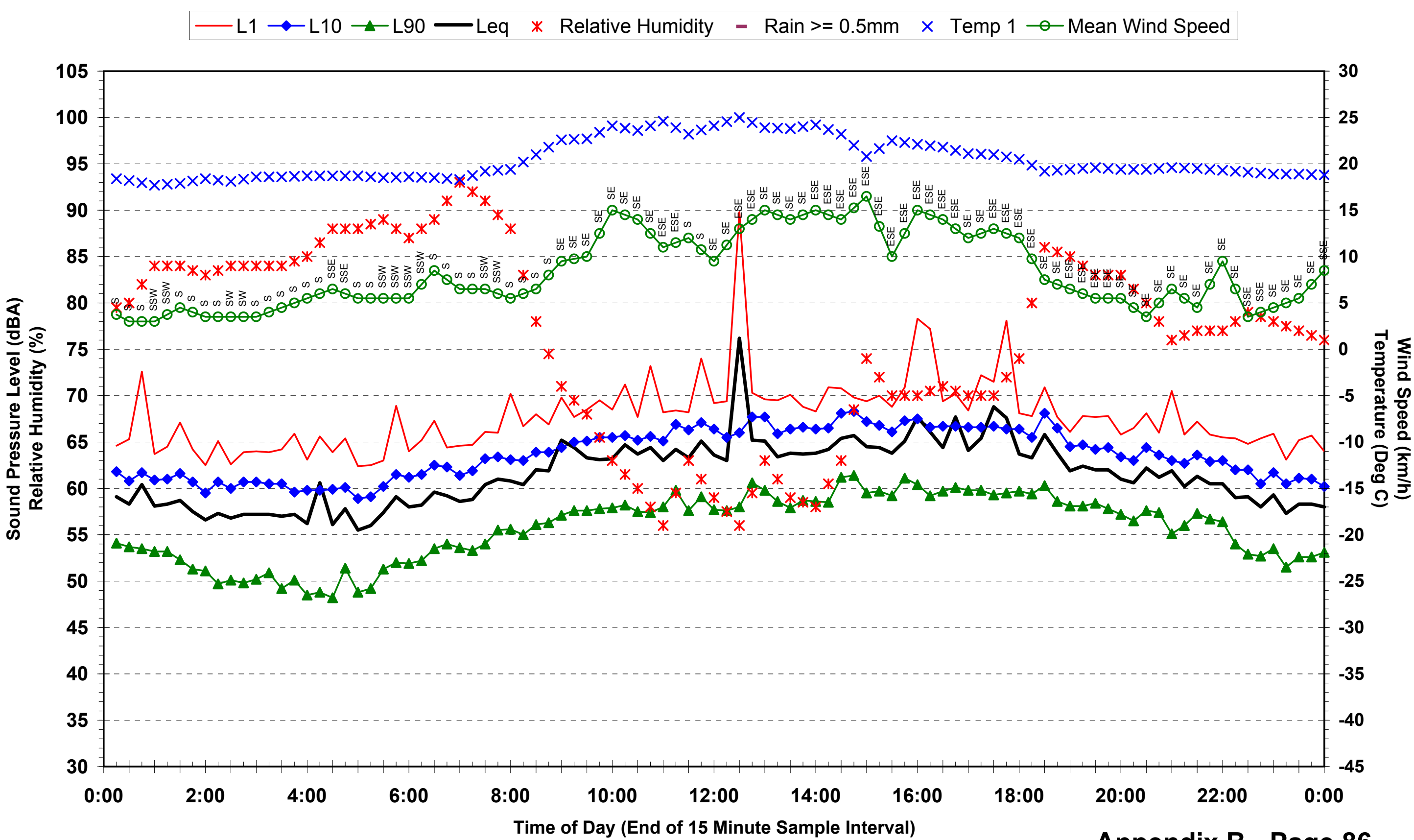
Appendix B - Page 84
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Saturday 10 November 2007



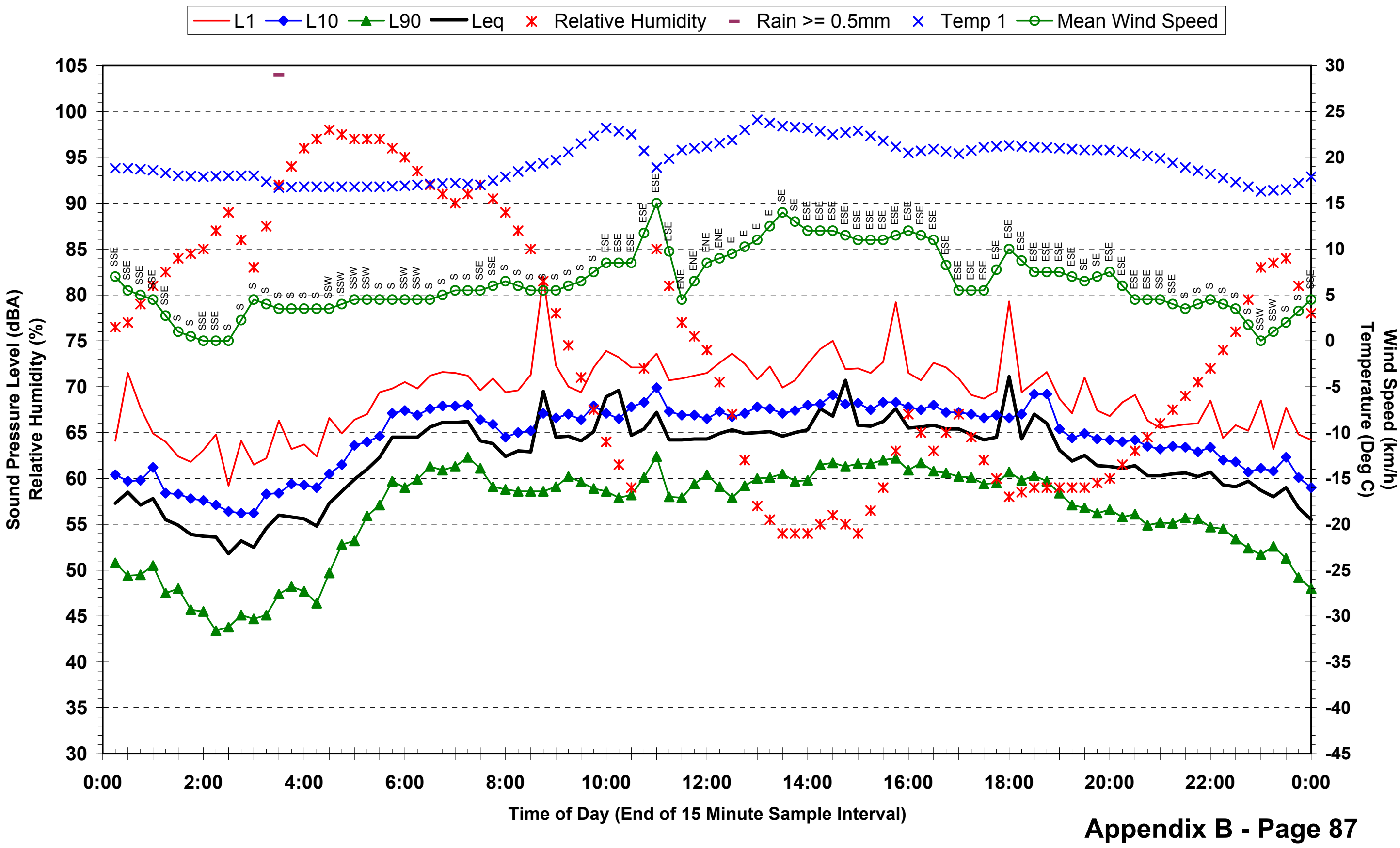
Appendix B - Page 85
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Sunday 11 November 2007



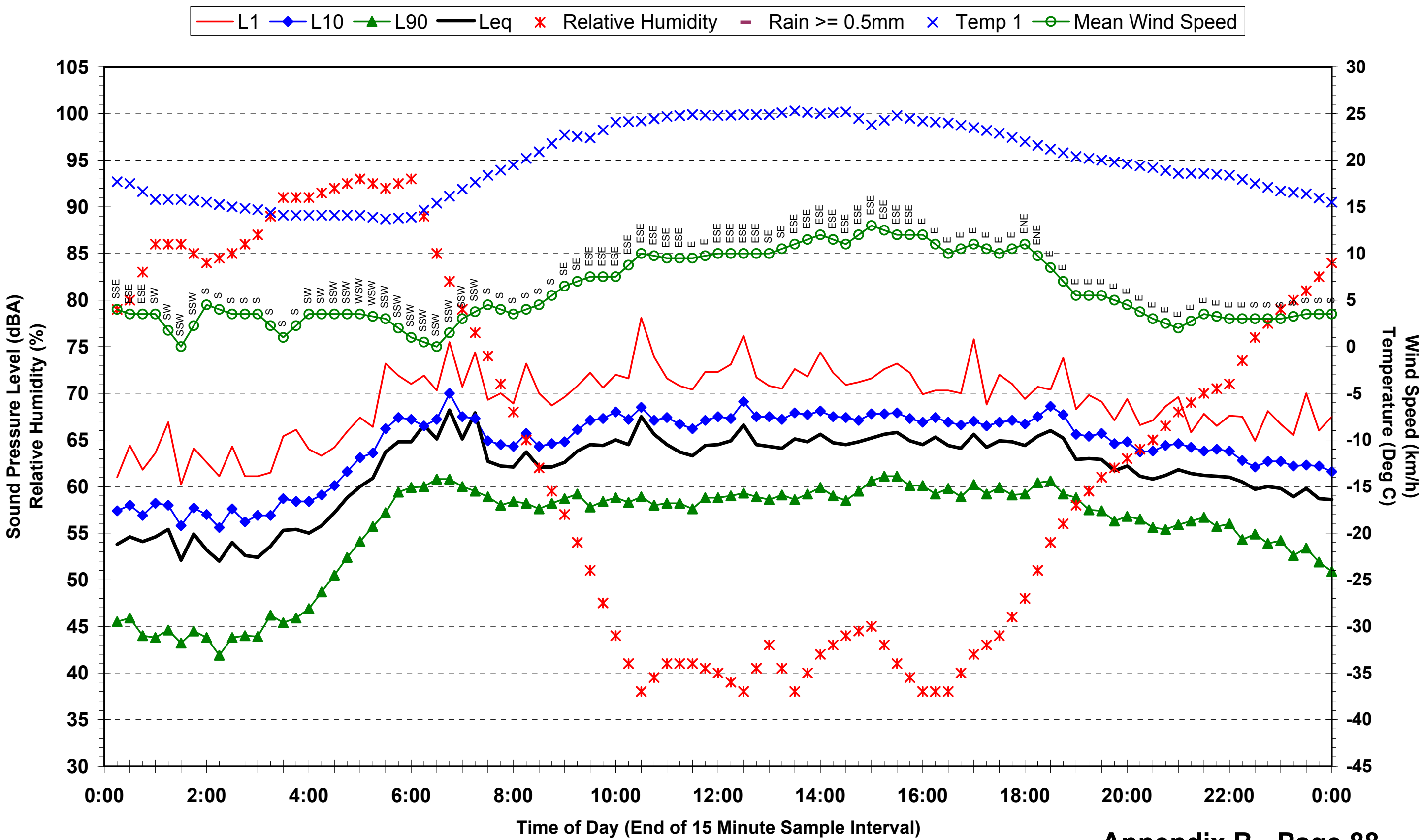
Appendix B - Page 86
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Monday 12 November 2007



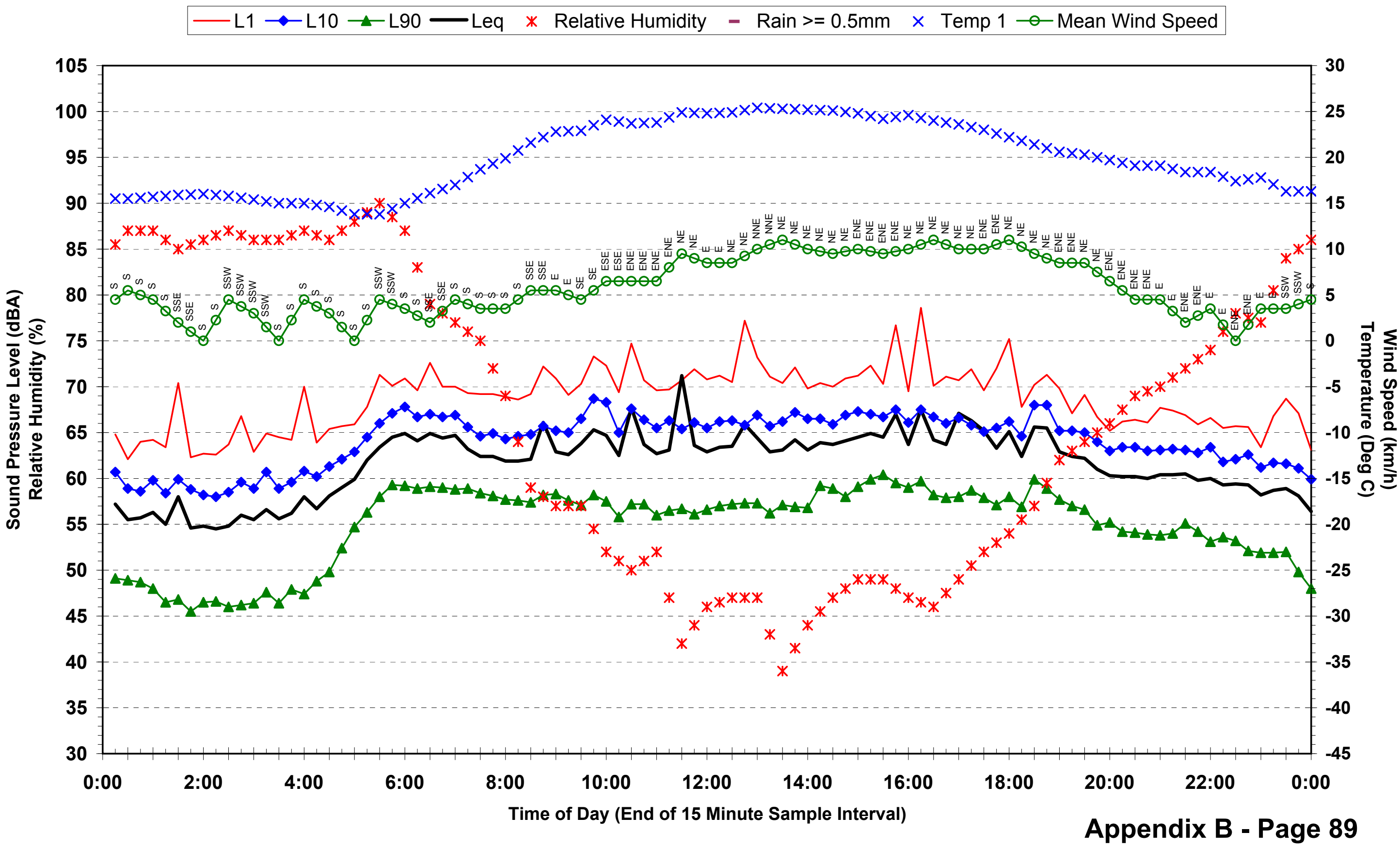
Appendix B - Page 87
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Tuesday 13 November 2007



Appendix B - Page 88
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Wednesday 14 November 2007

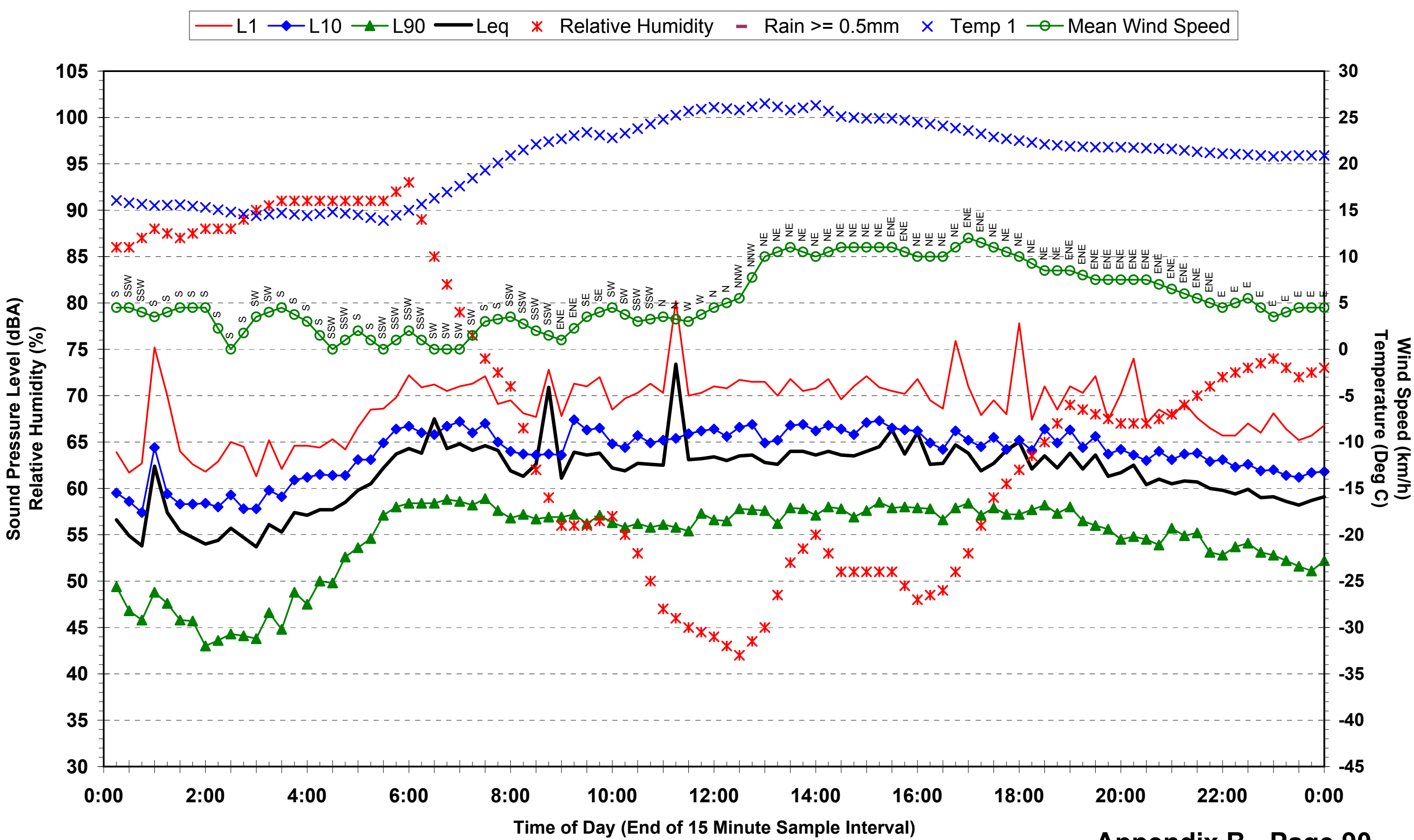


Appendix B - Page 89

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Thursday 15 November 2007

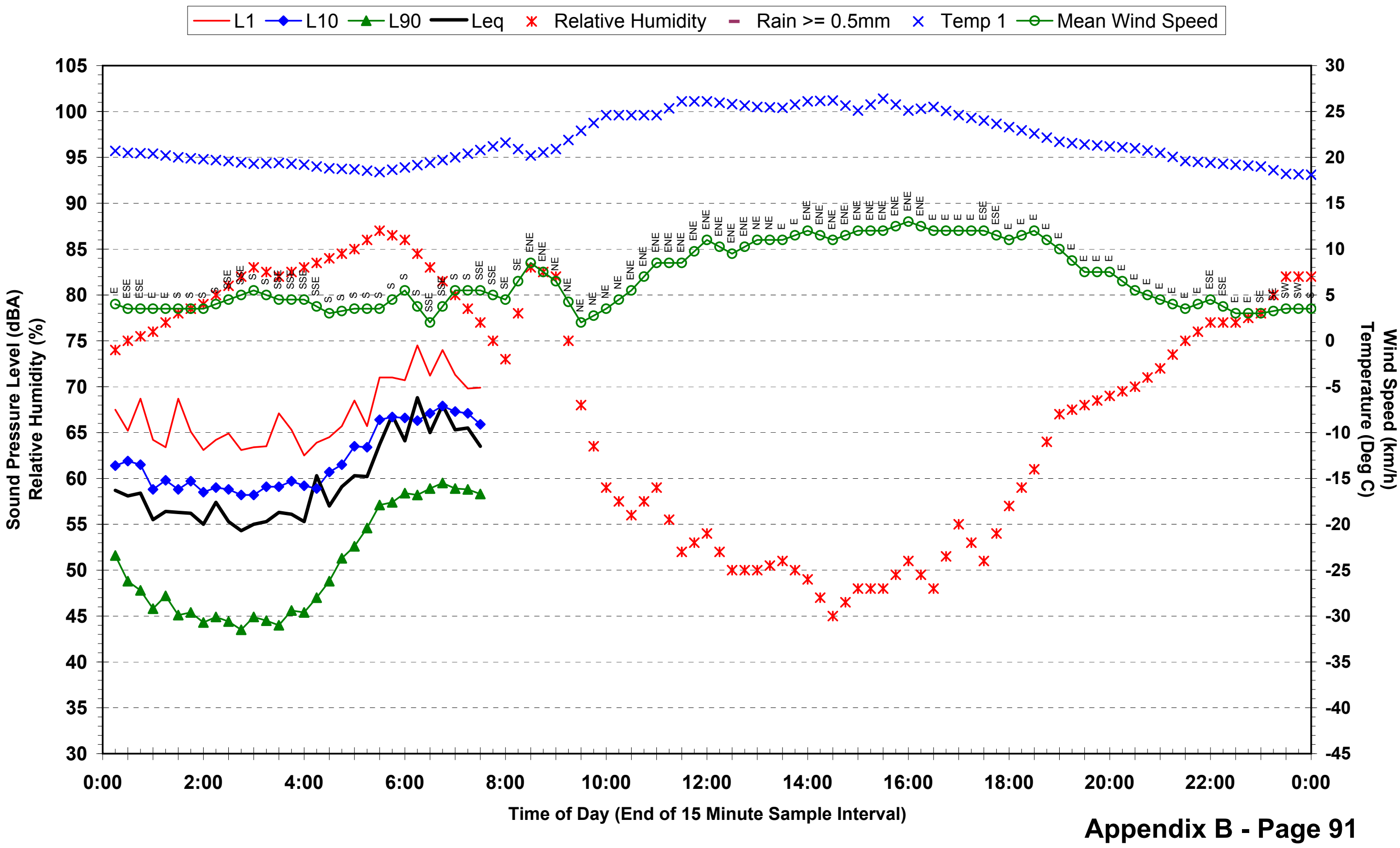


Appendix B - Page 90

Ambient Conditions

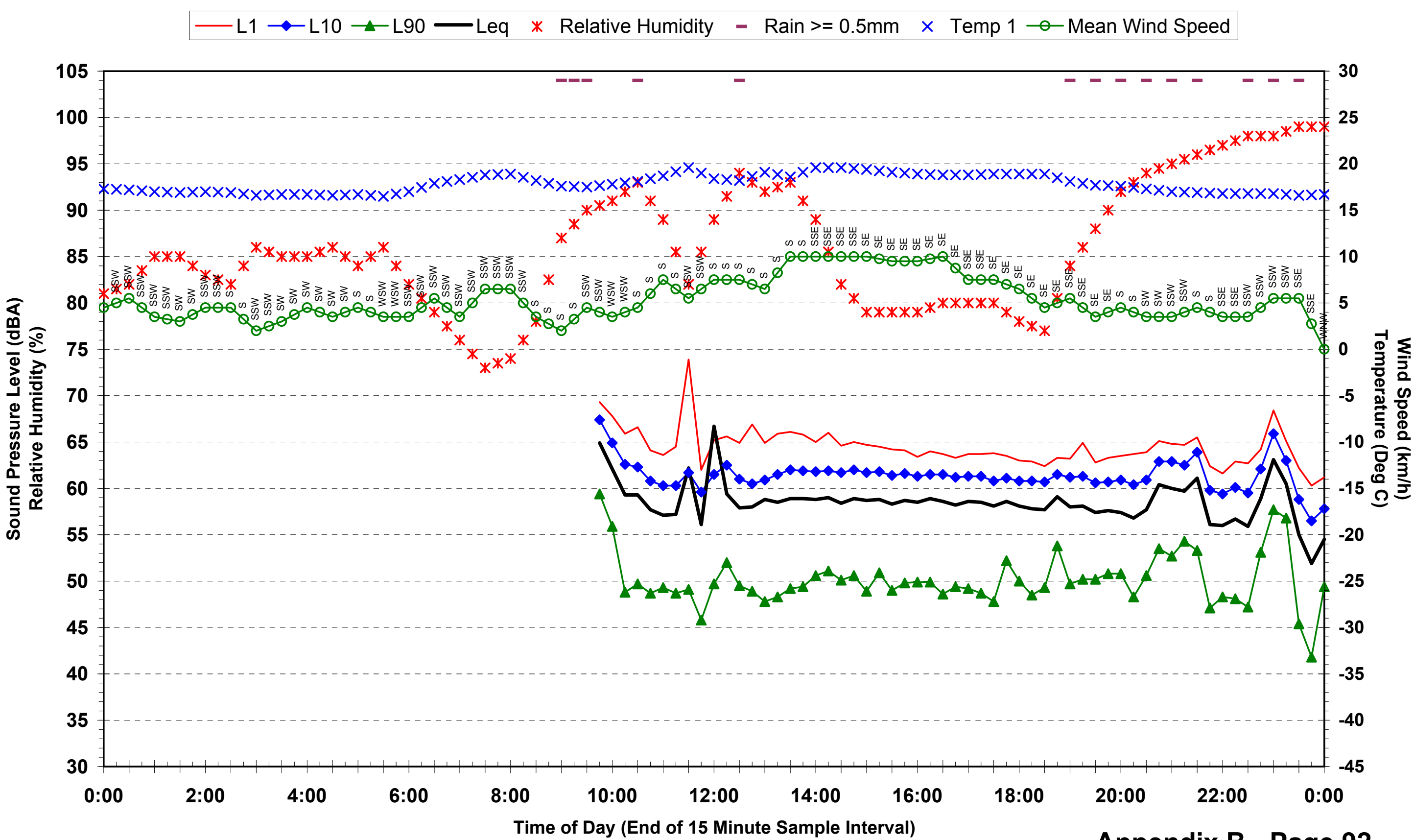
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 9 - 26 Lower Clifton Terrace, Red Hill - Friday 16 November 2007



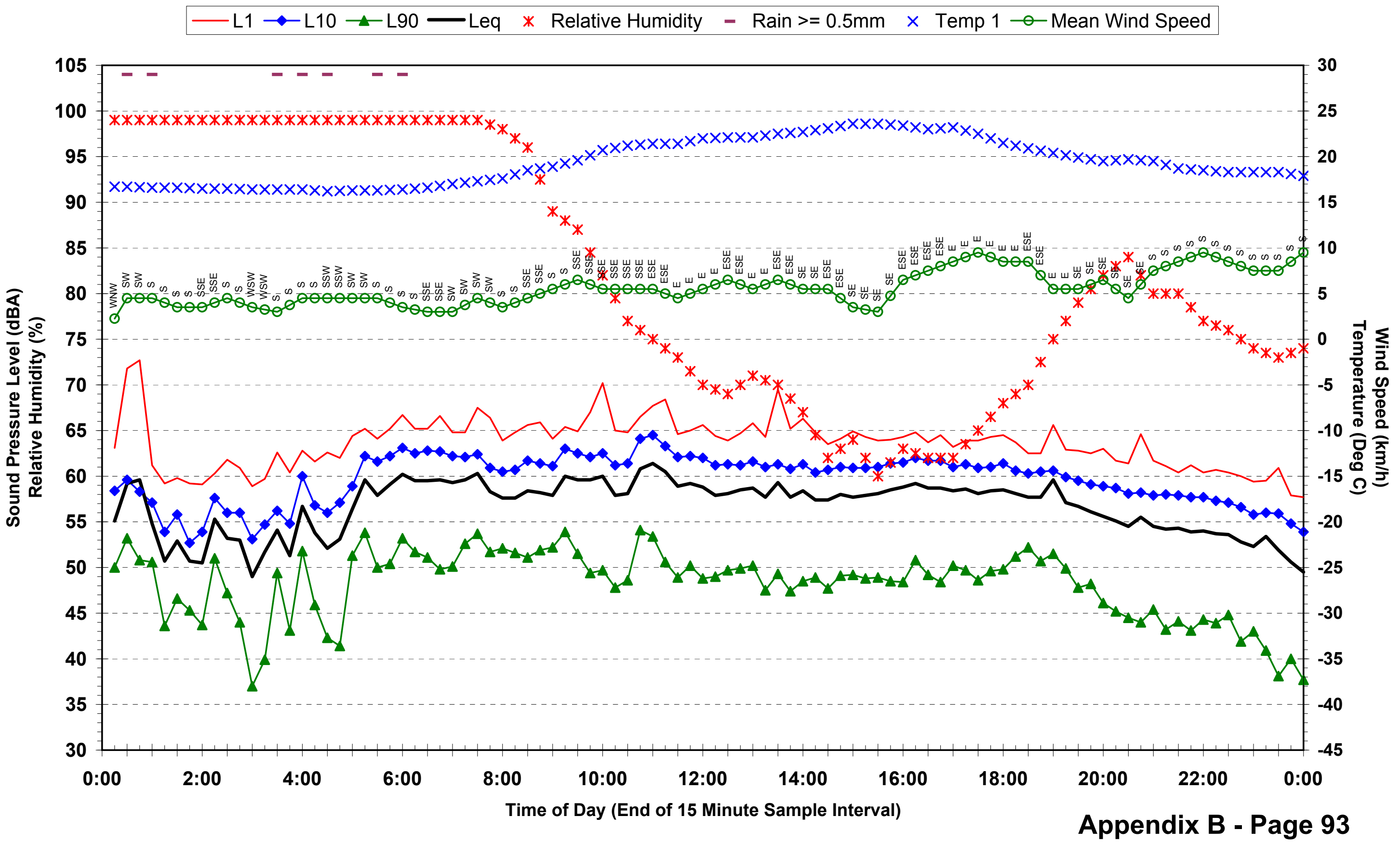
Appendix B - Page 91
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Wednesday 7 November 2007



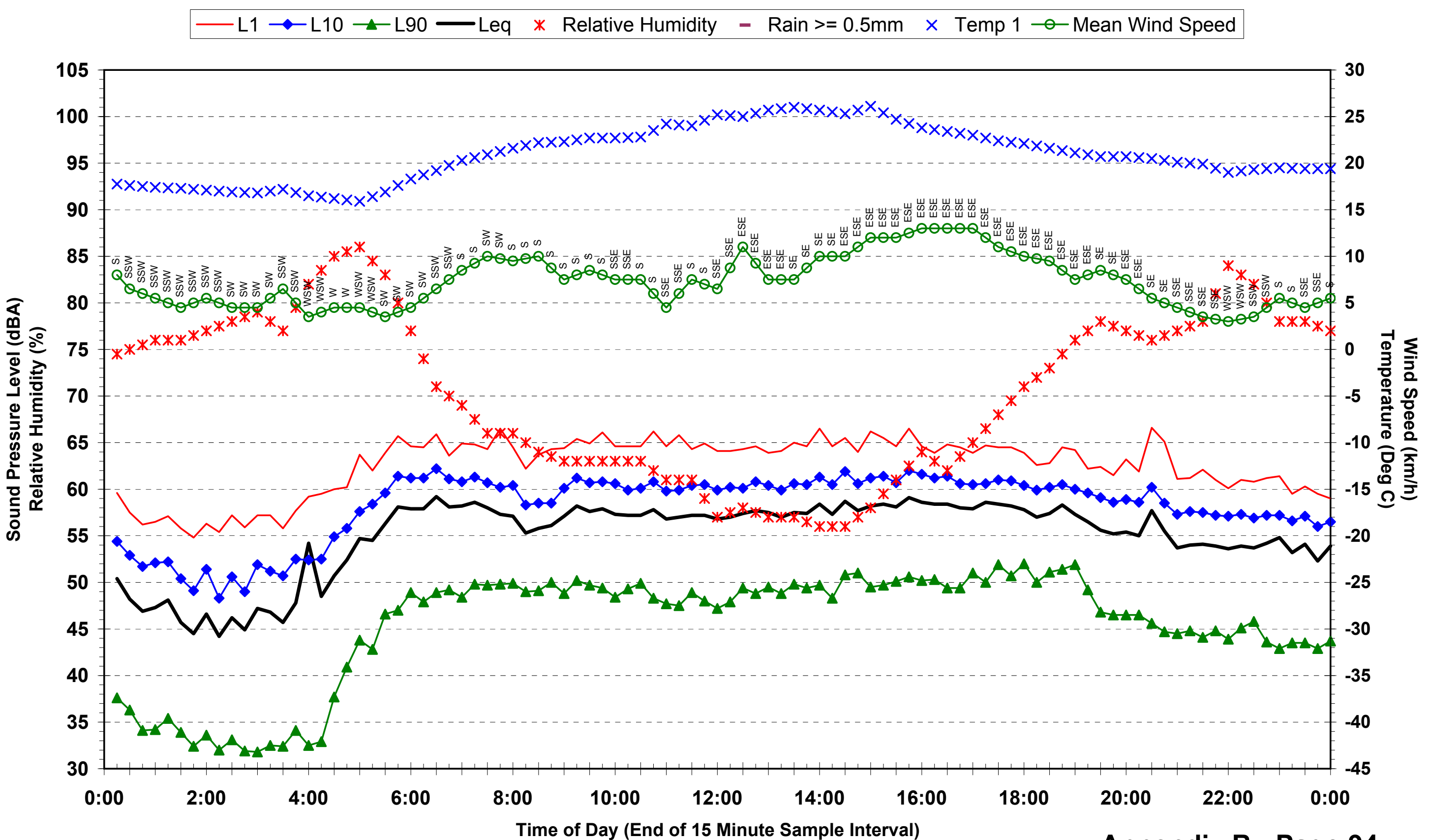
Appendix B - Page 92
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Thursday 8 November 2007



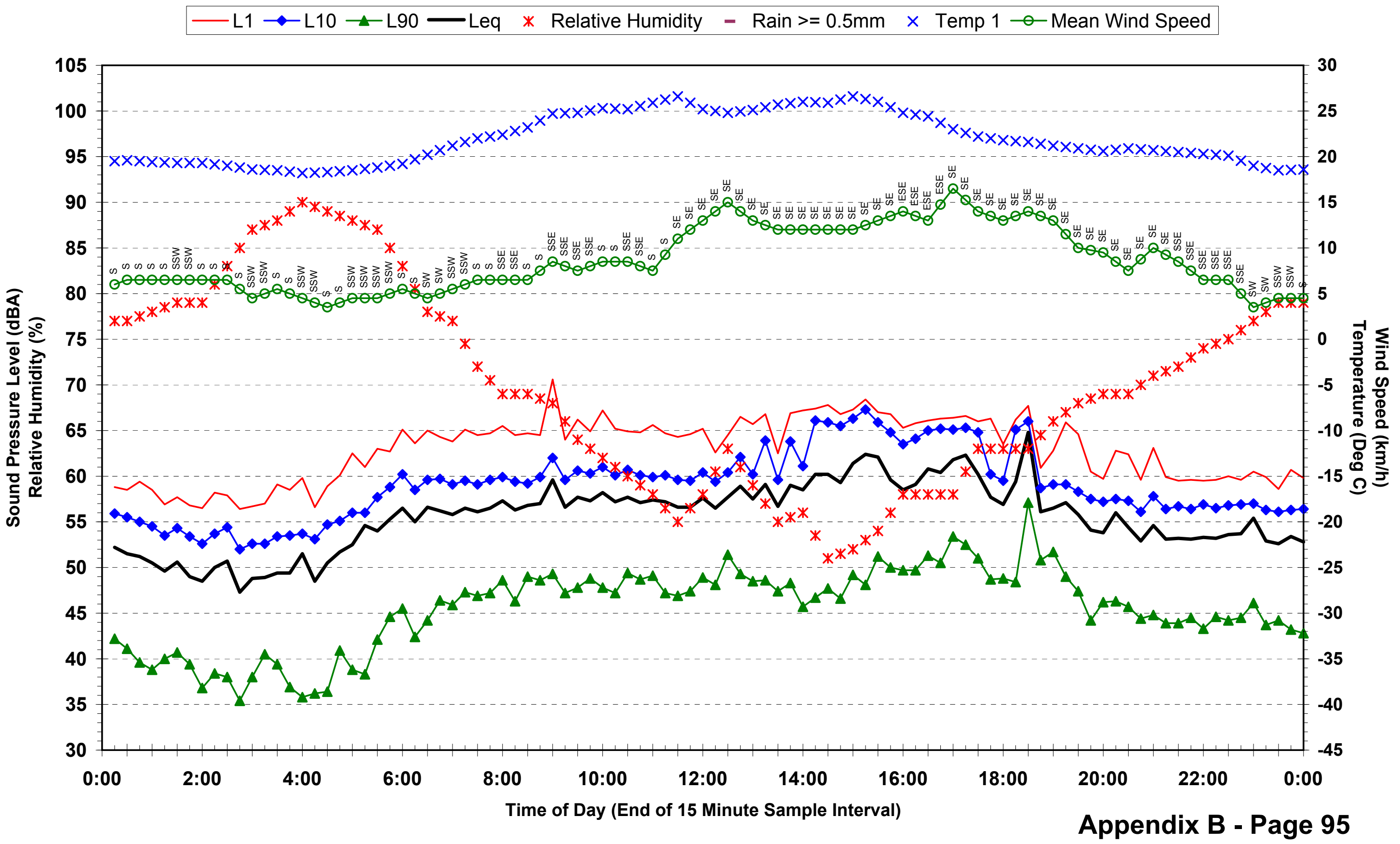
Appendix B - Page 93
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Friday 9 November 2007



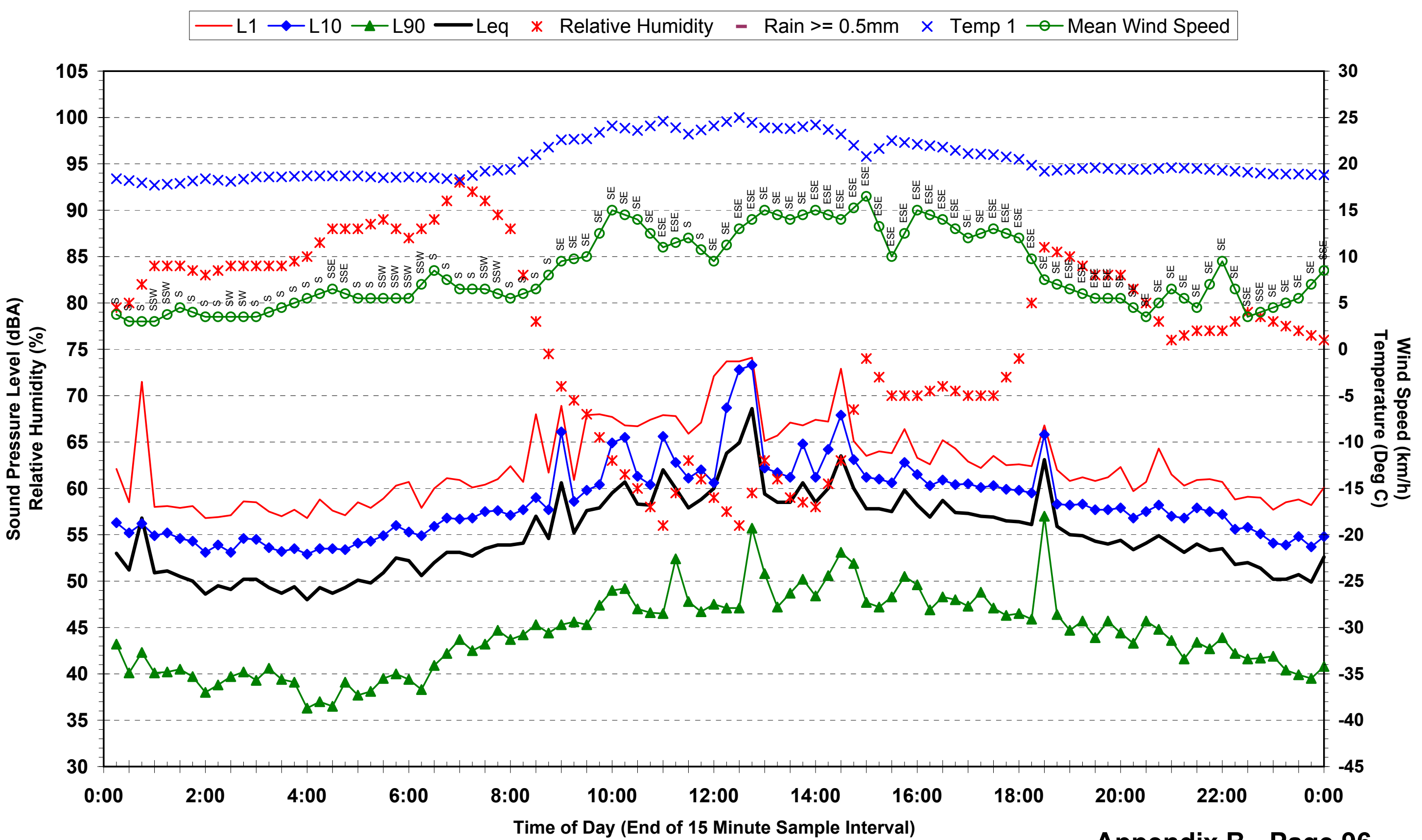
Appendix B - Page 94
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Saturday 10 November 2007



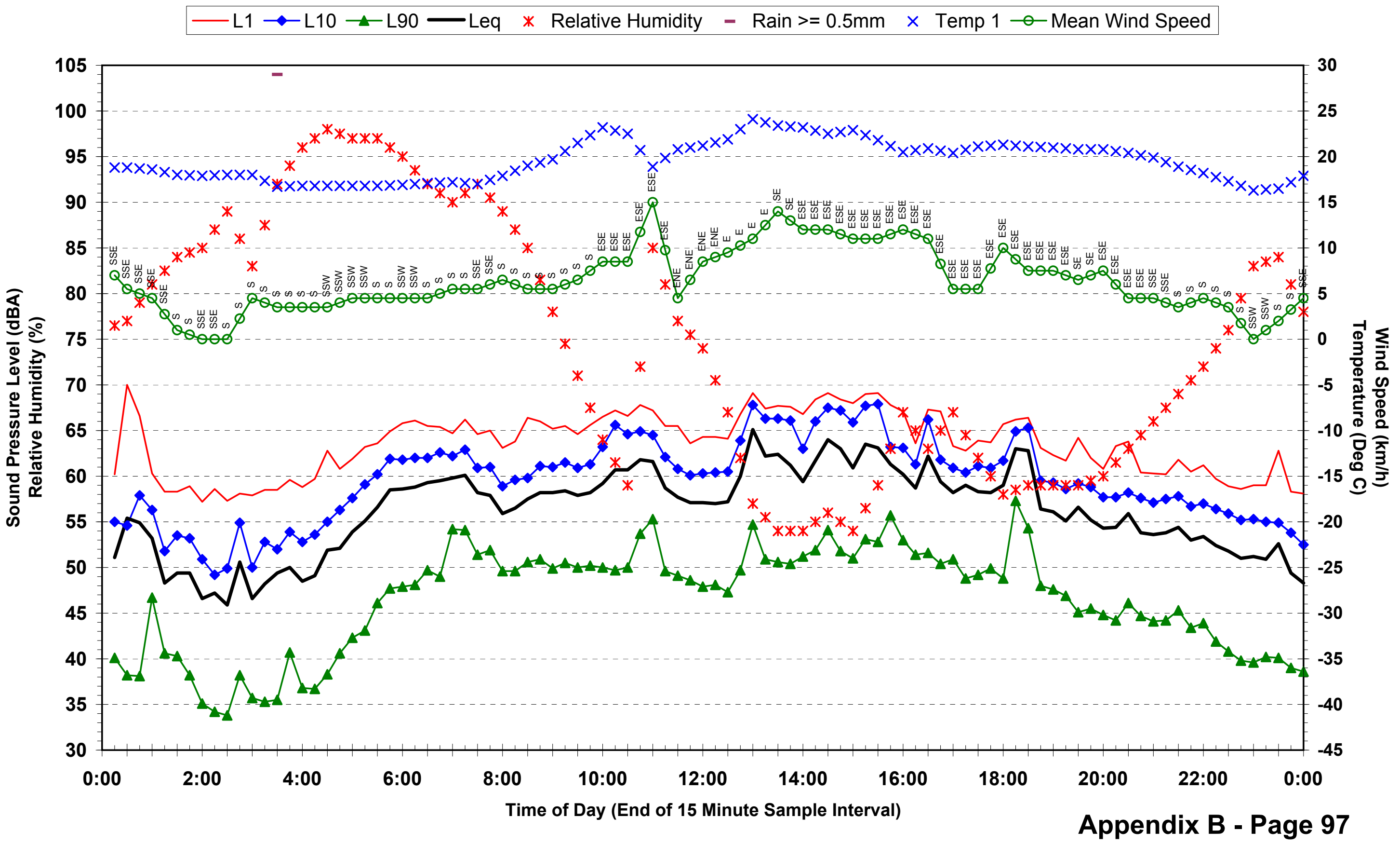
Appendix B - Page 95
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Sunday 11 November 2007



Appendix B - Page 96
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Monday 12 November 2007

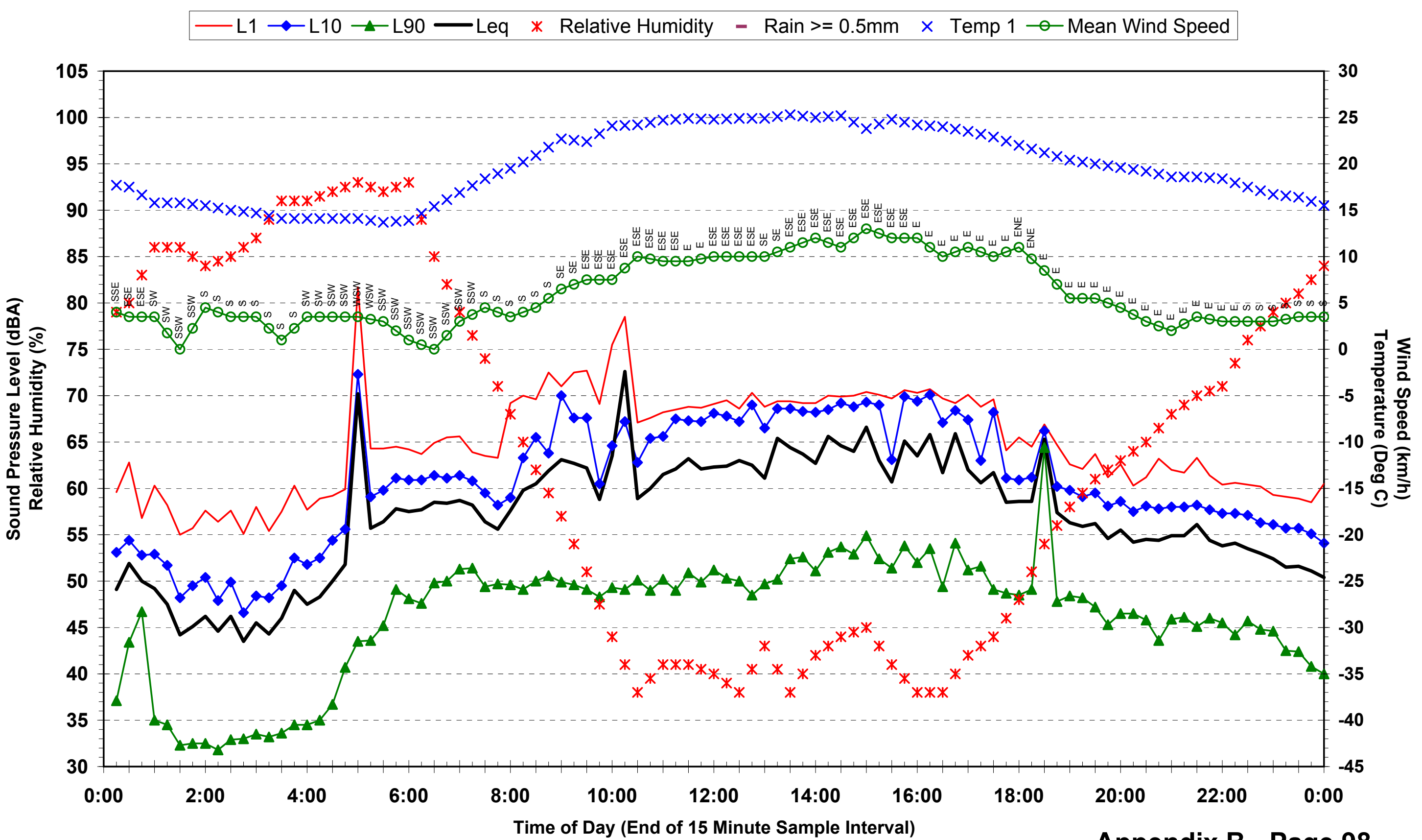


Appendix B - Page 97

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Tuesday 13 November 2007

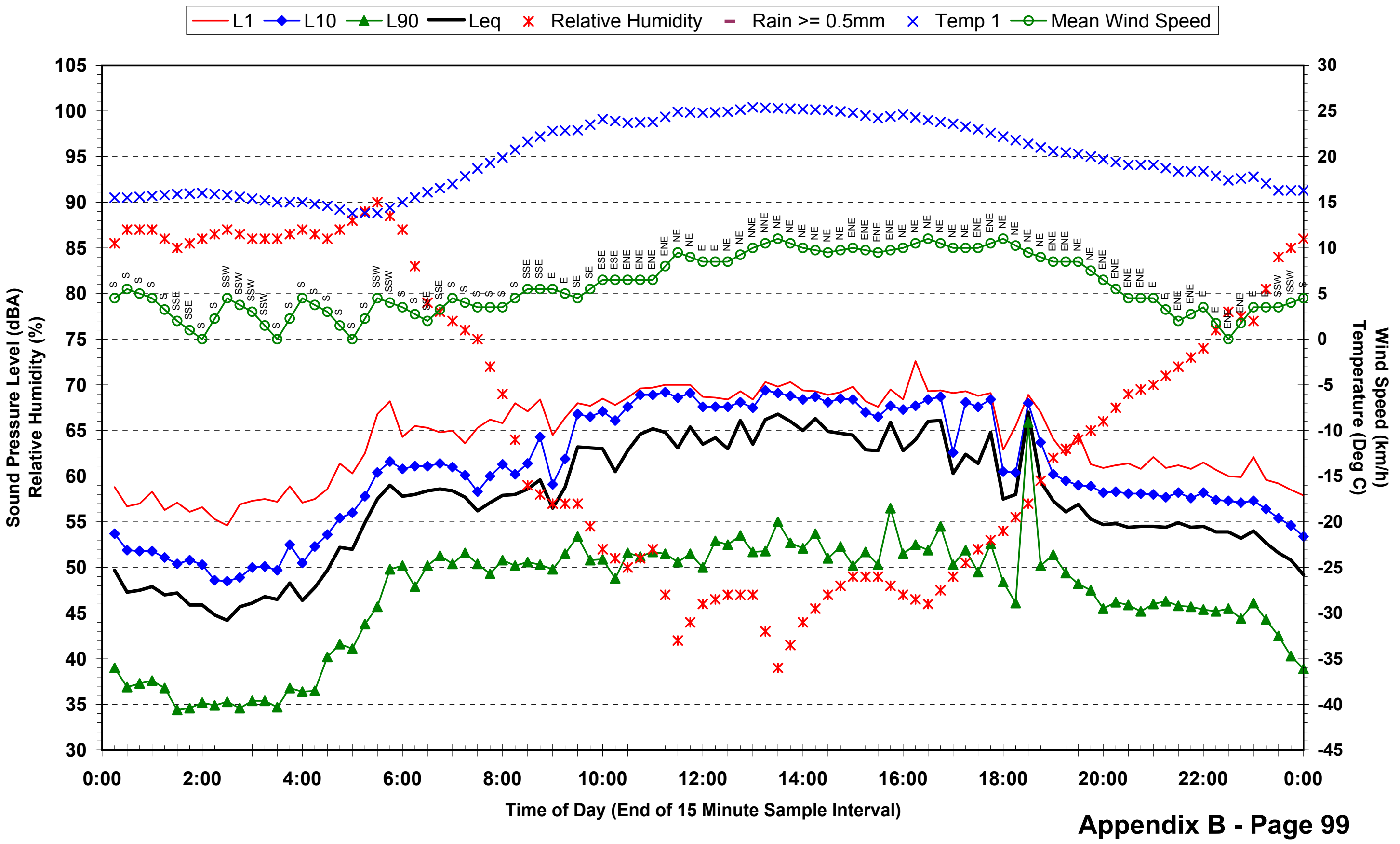


Appendix B - Page 98

Ambient Conditions

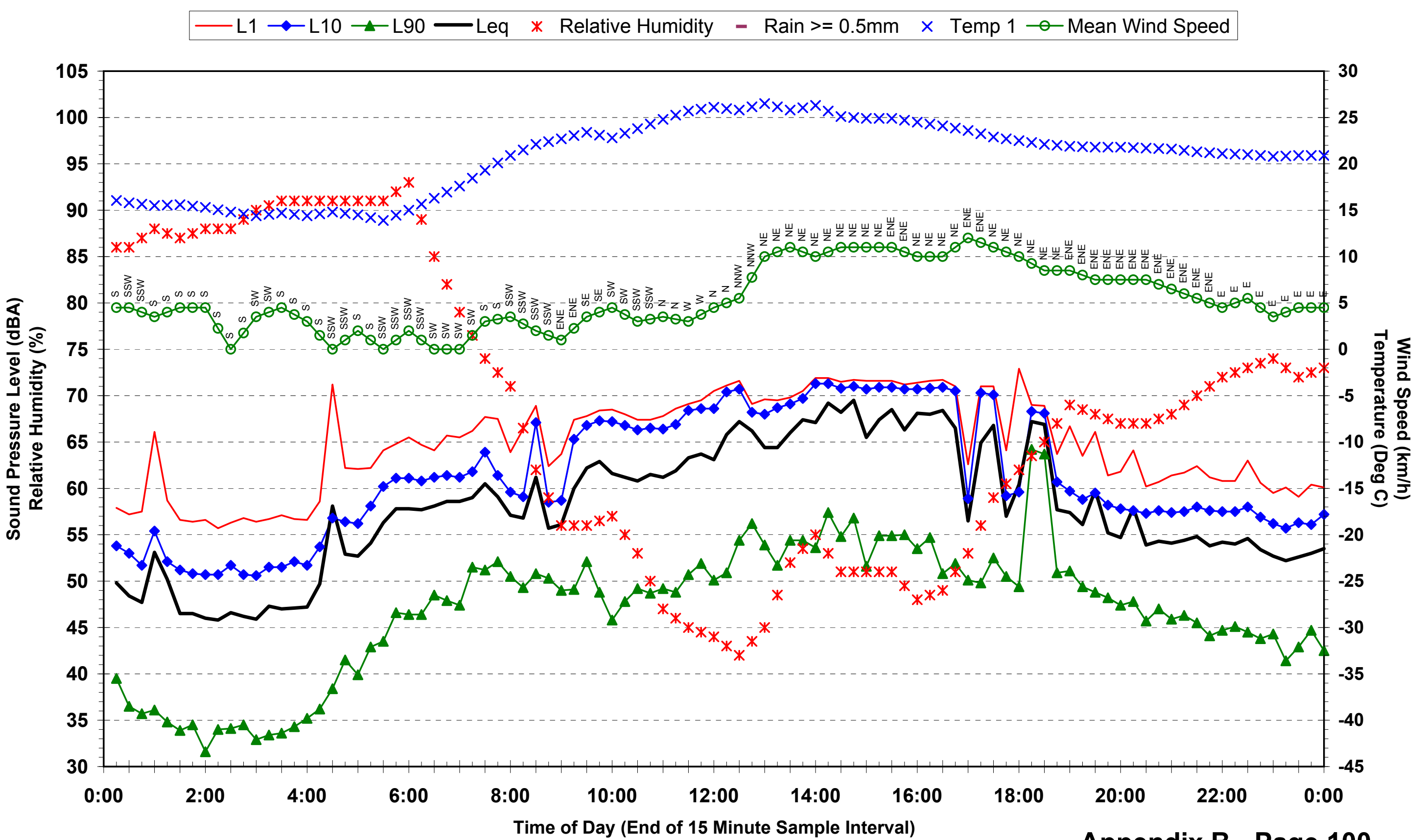
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Wednesday 14 November 2007



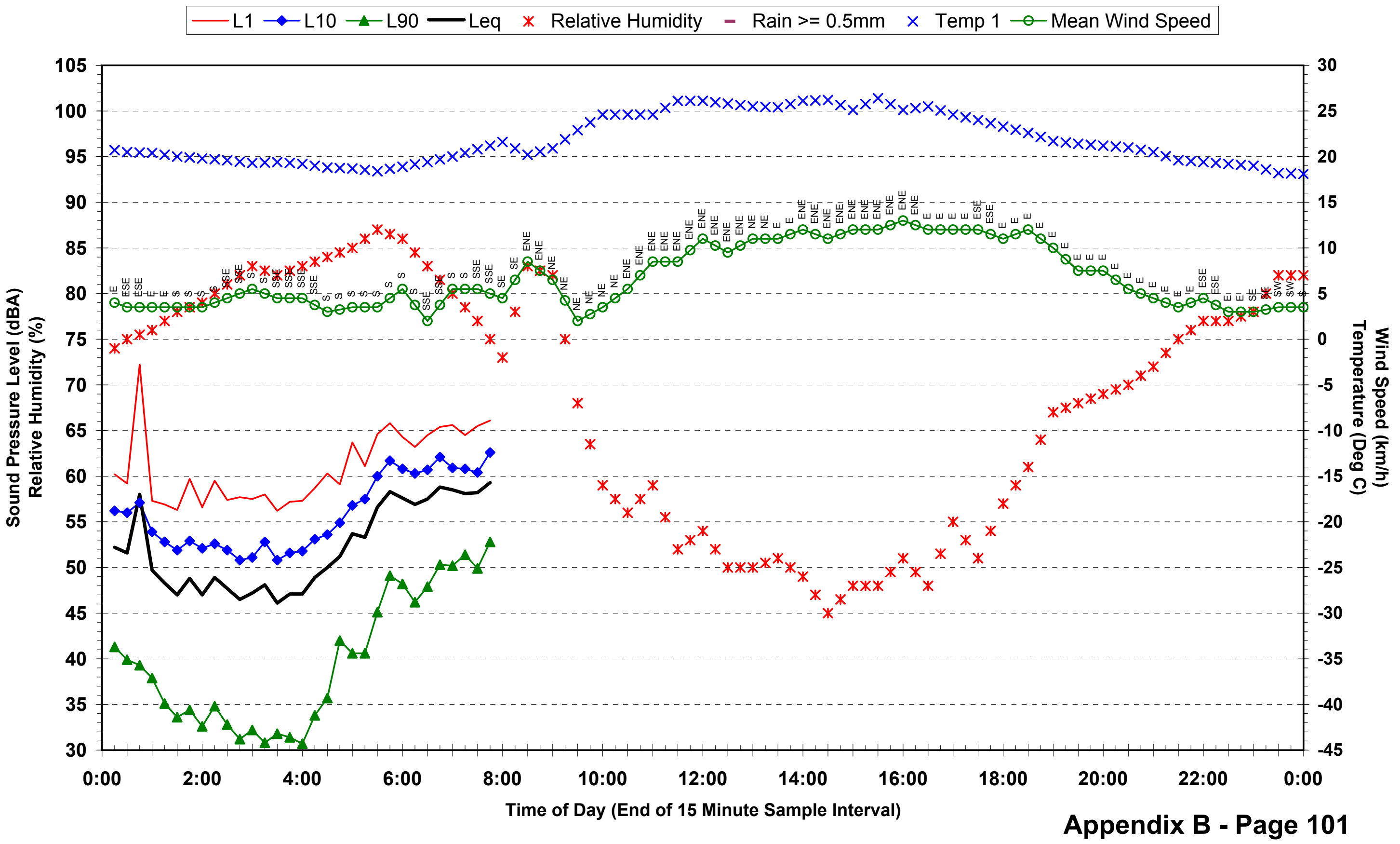
Appendix B - Page 99
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Thursday 15 November 2007



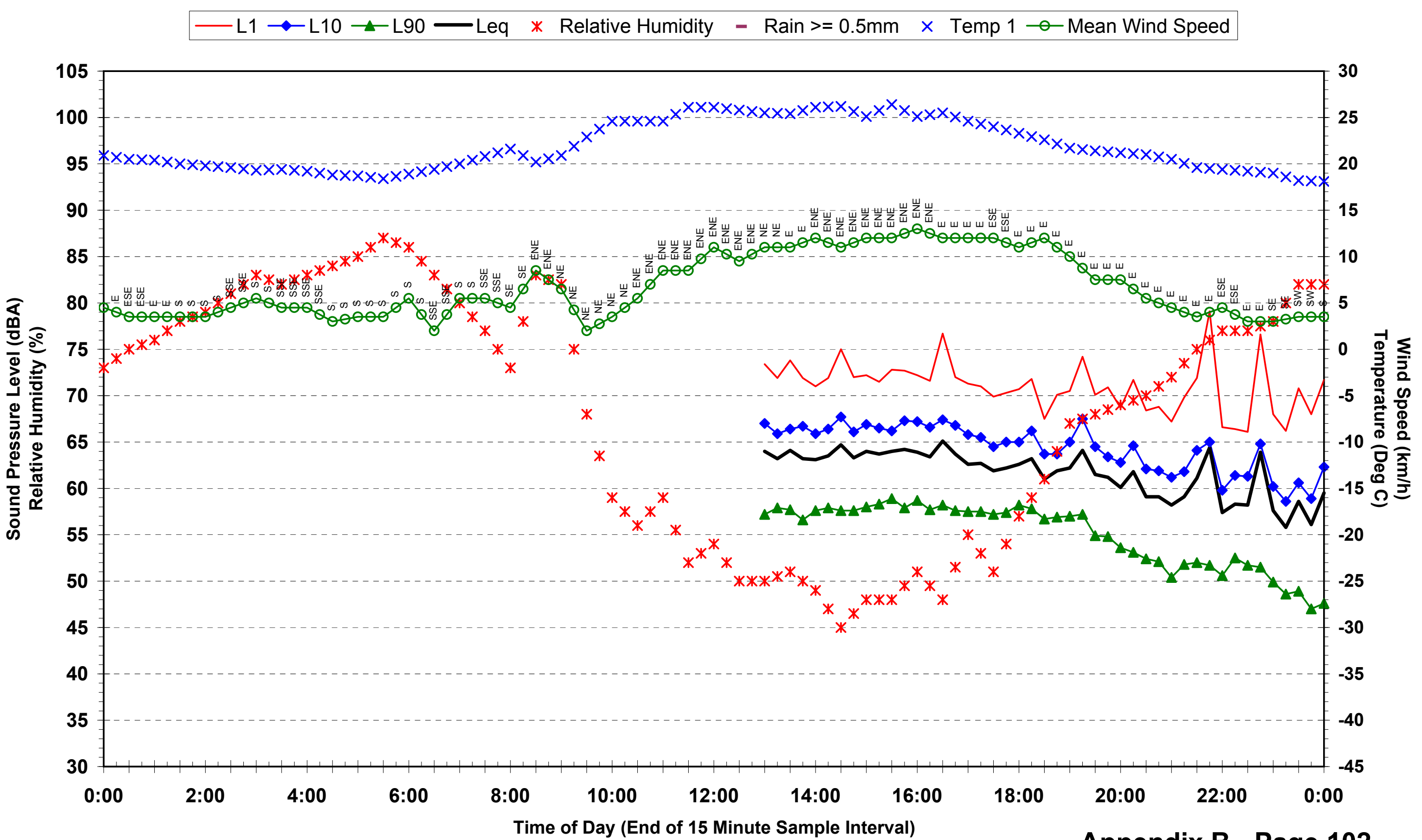
Appendix B - Page 100
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 10 - 7 Westbury Street, Red Hill - Friday 16 November 2007



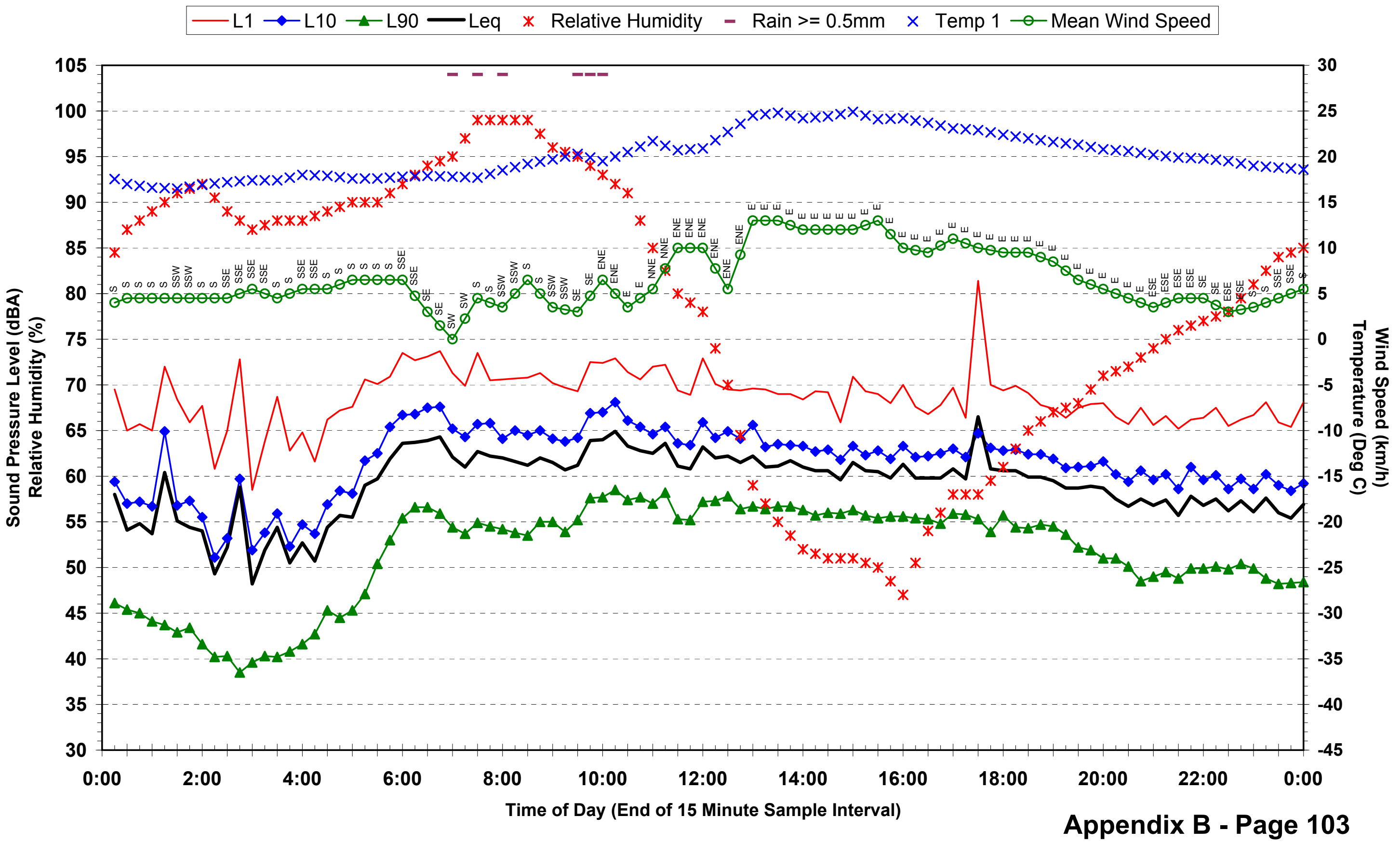
Appendix B - Page 101
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Friday 16 November 2007



Appendix B - Page 102
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Saturday 17 November 2007

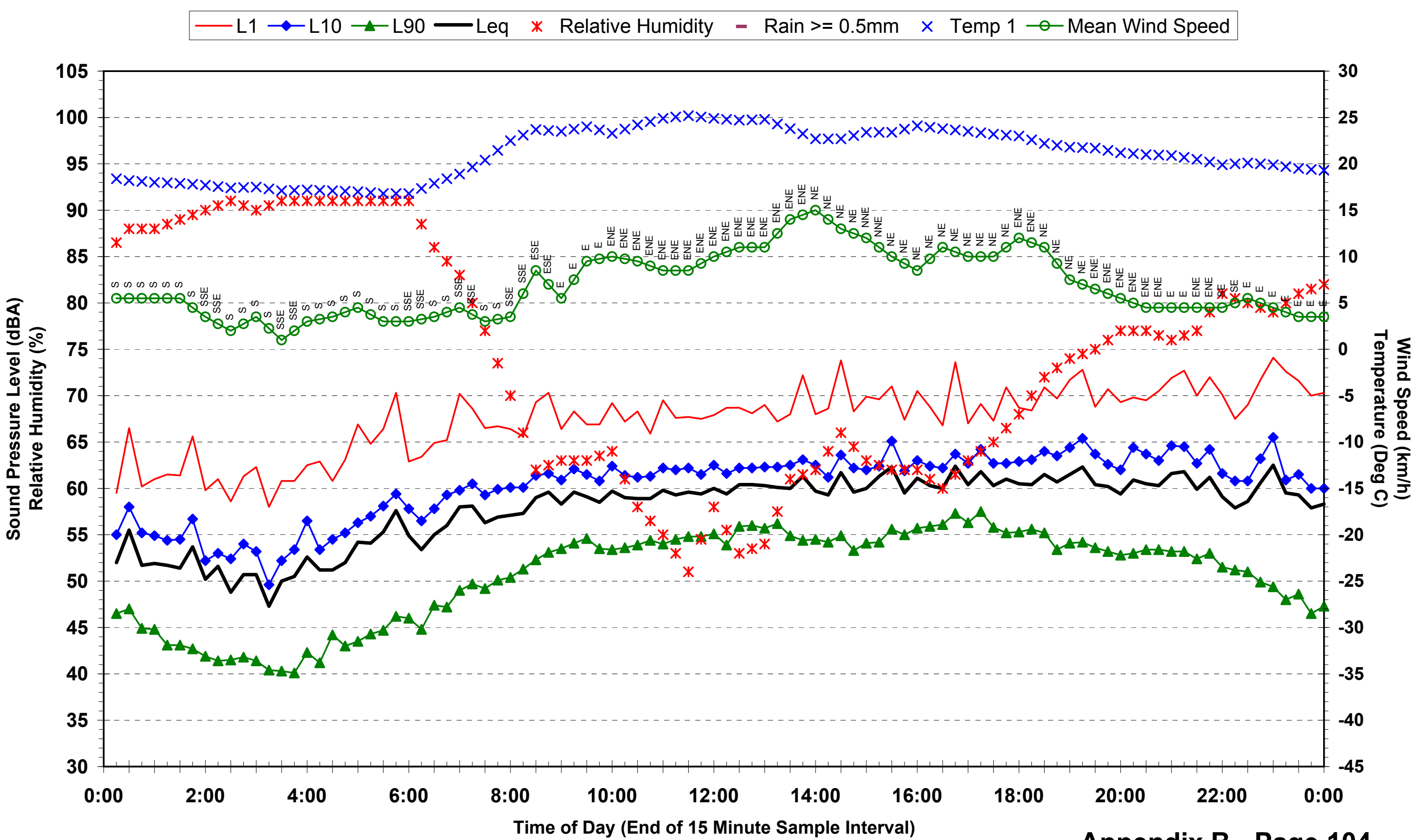


Appendix B - Page 103

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Sunday 18 November 2007

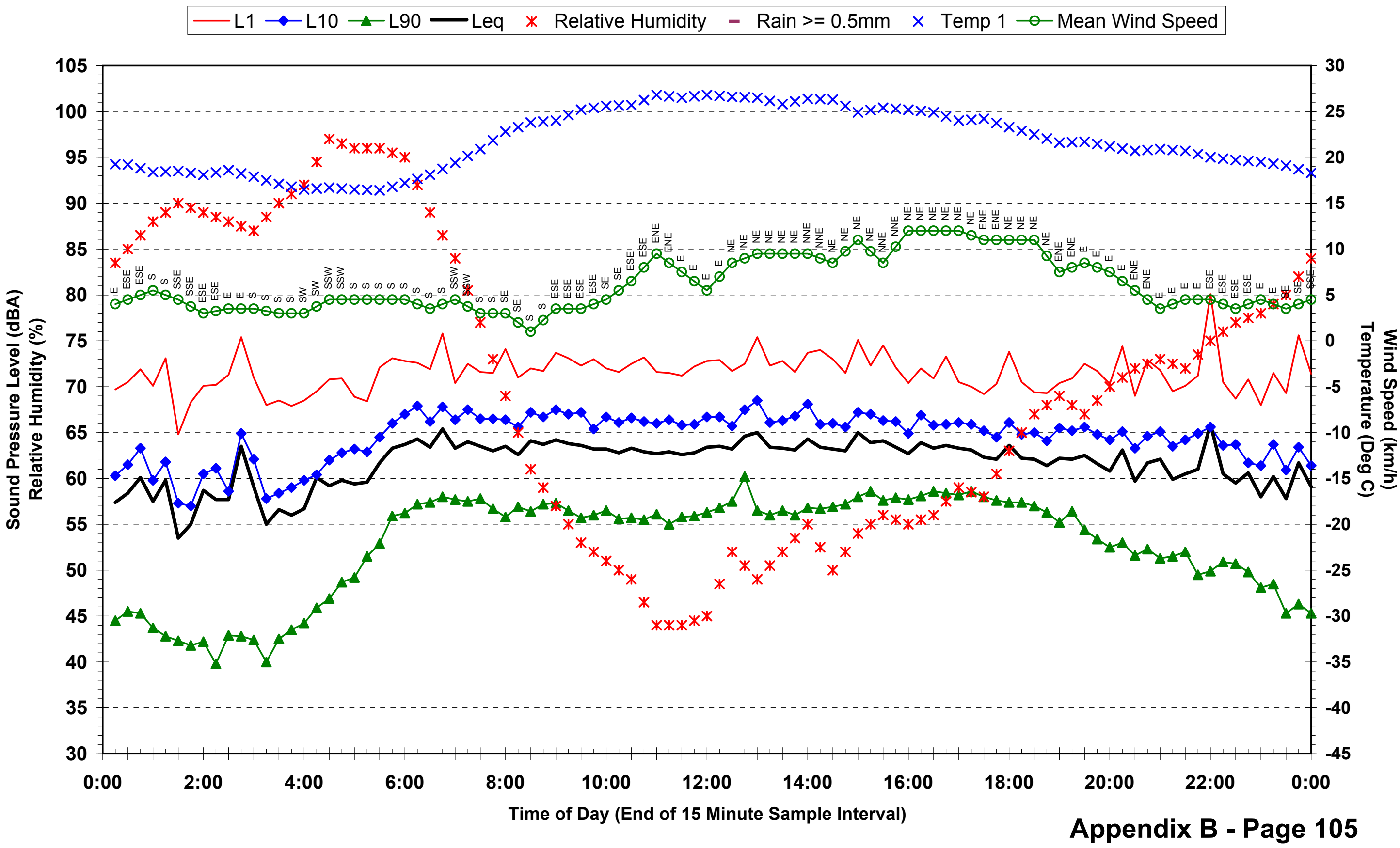


Appendix B - Page 104

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Monday 19 November 2007

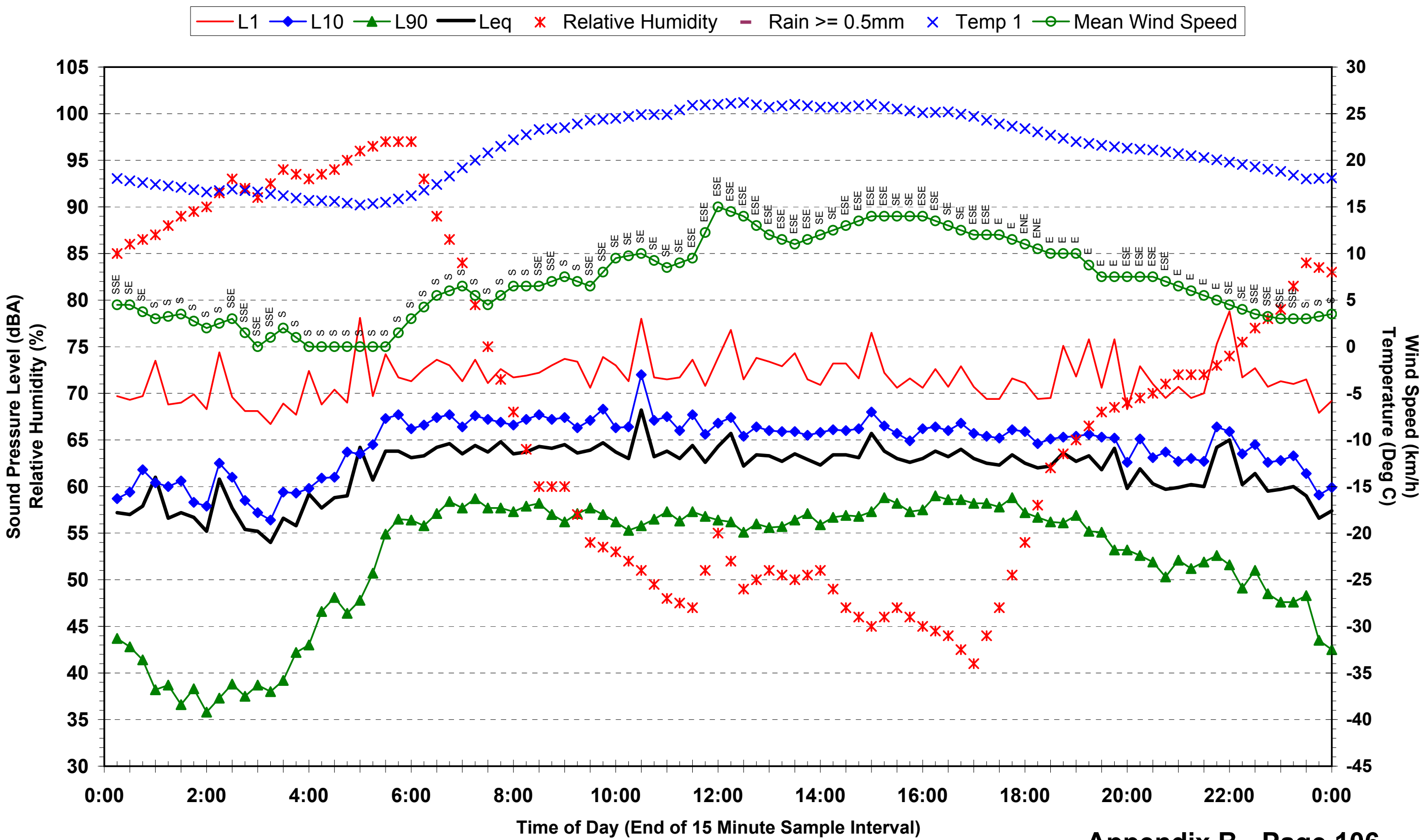


Appendix B - Page 105

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Tuesday 20 November 2007

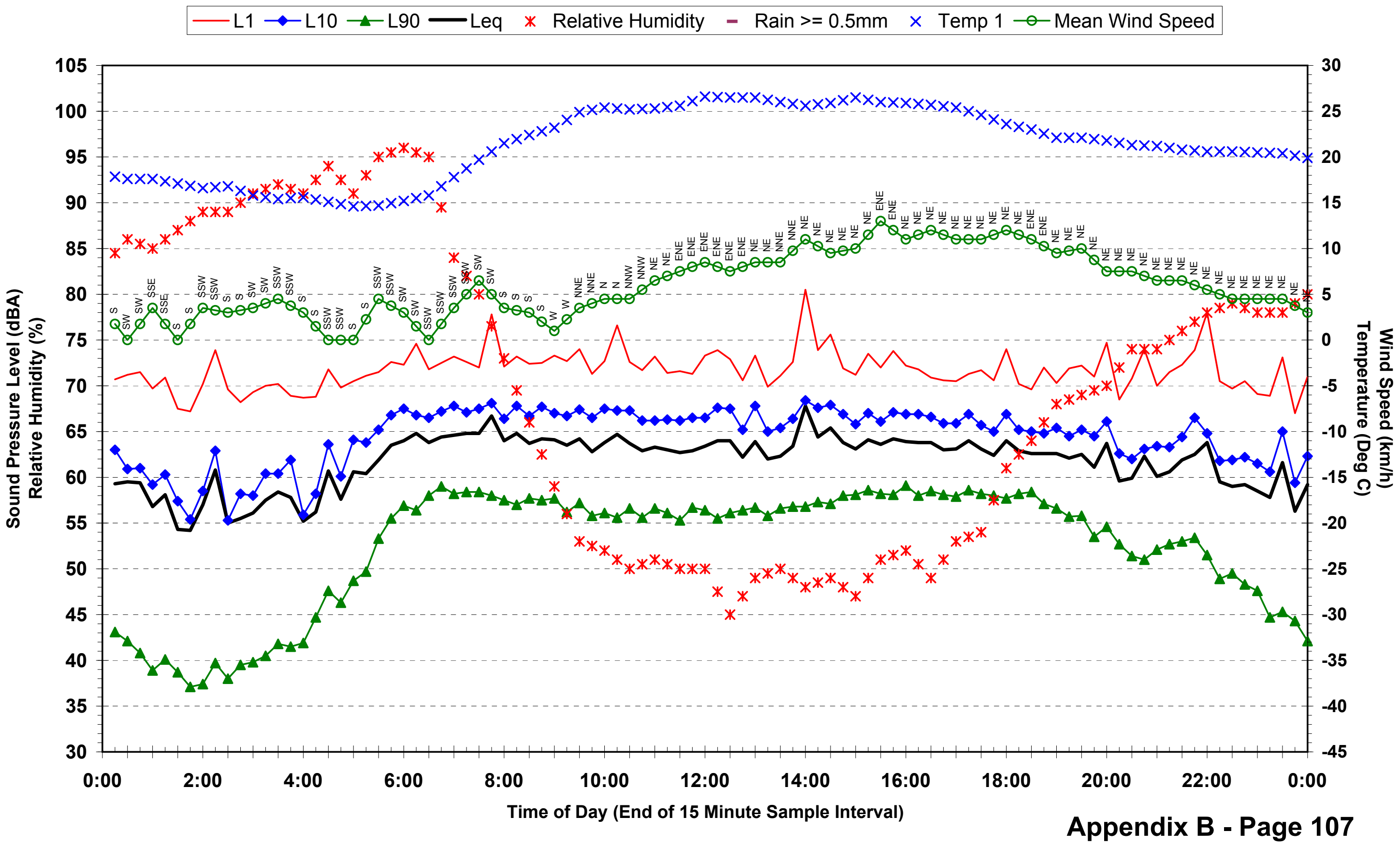


Appendix B - Page 106

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Wednesday 21 November 2007

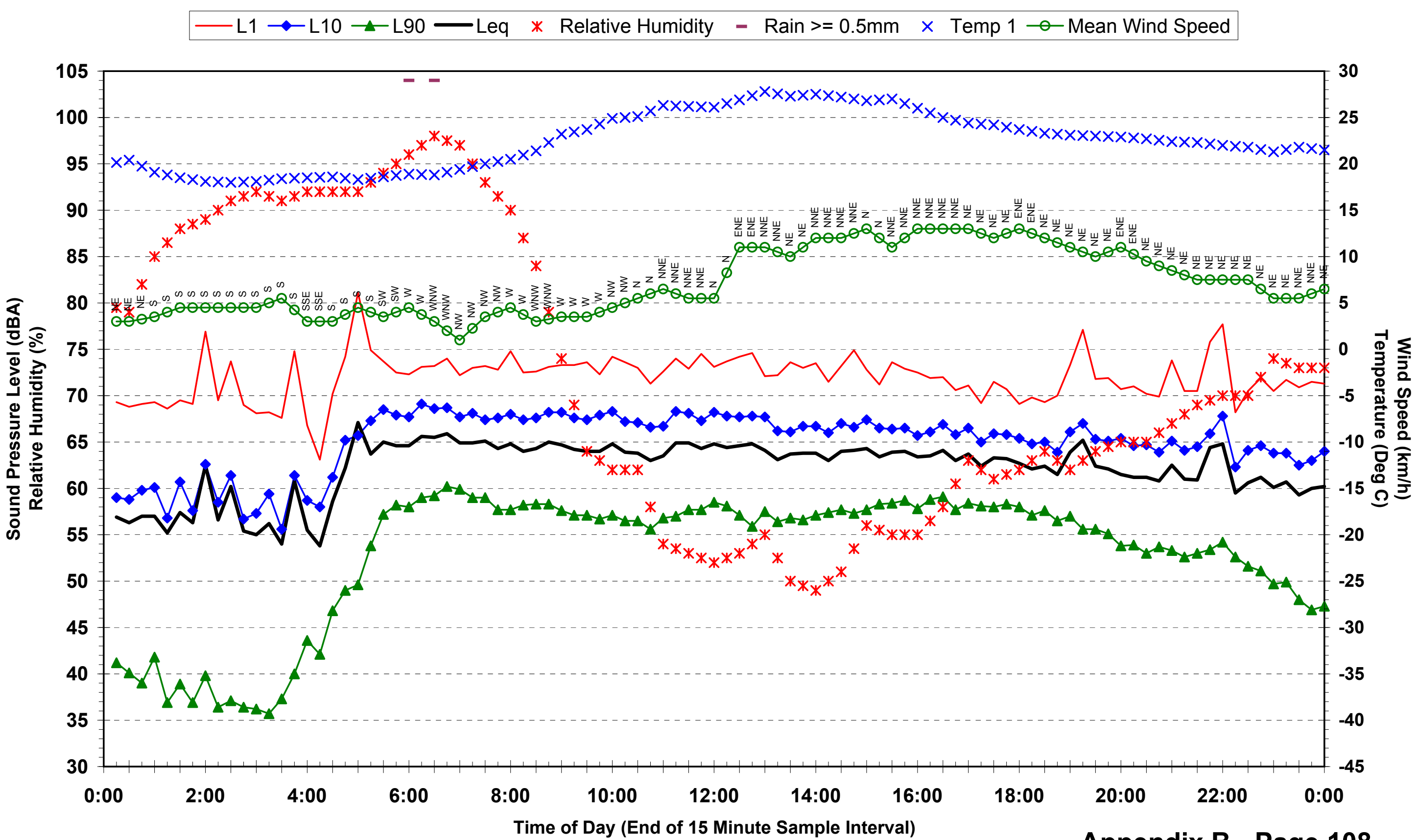


Appendix B - Page 107

Ambient Conditions

Heggies Report 20-1854

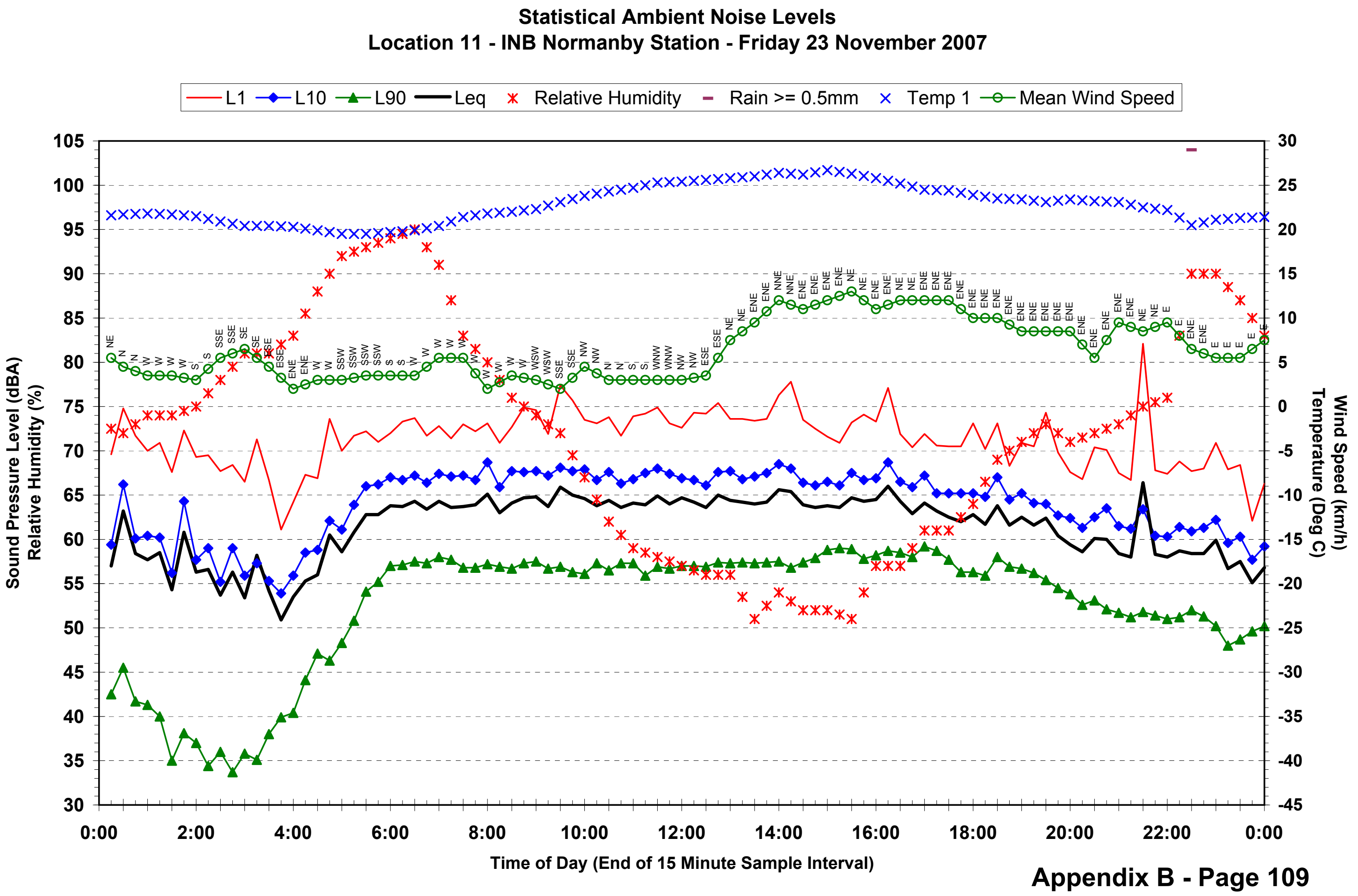
Statistical Ambient Noise Levels
Location 11 - INB Normanby Station - Thursday 22 November 2007



Appendix B - Page 108

Ambient Conditions

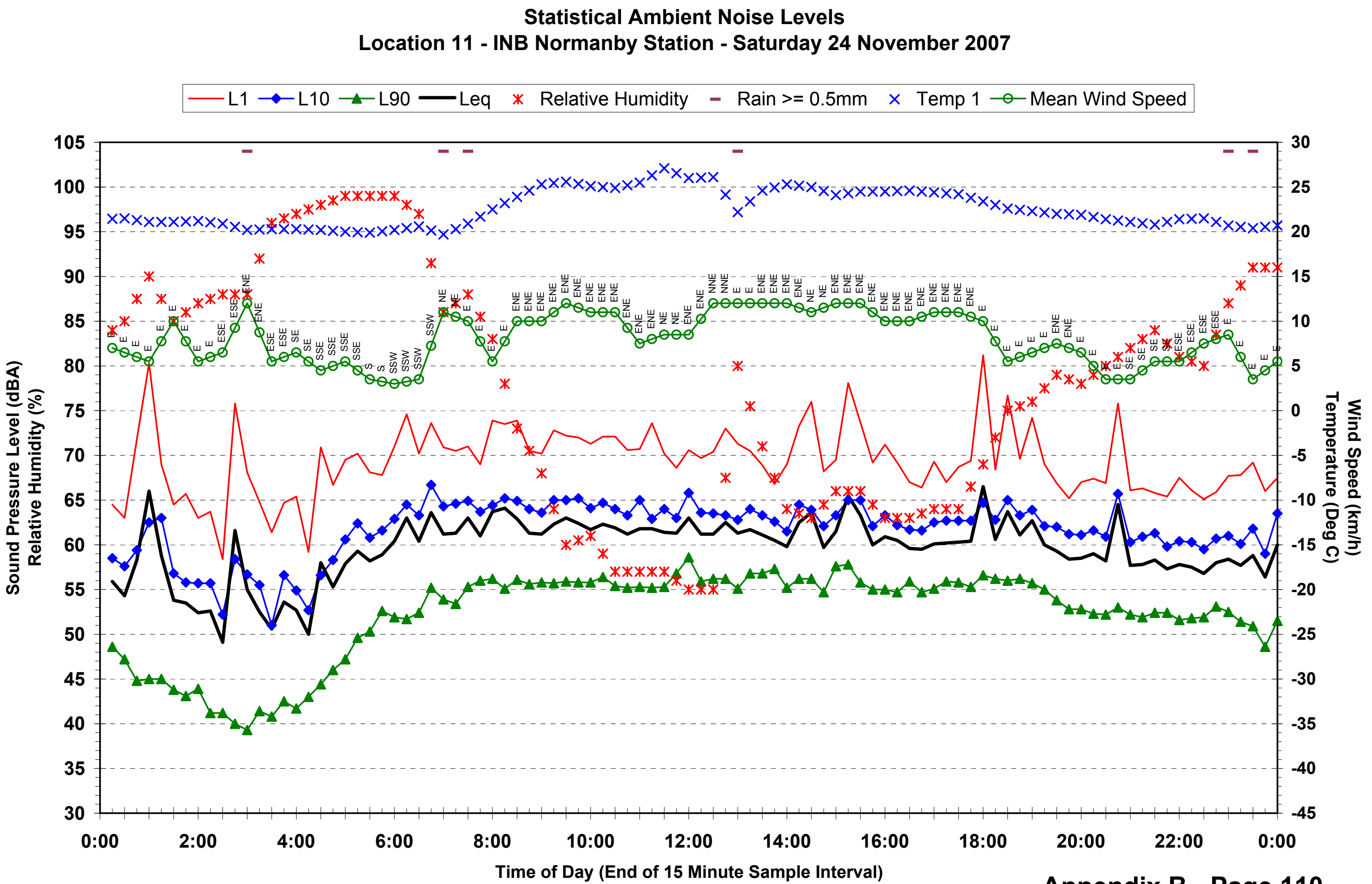
Heggies Report 20-1854



Appendix B - Page 109

Ambient Conditions

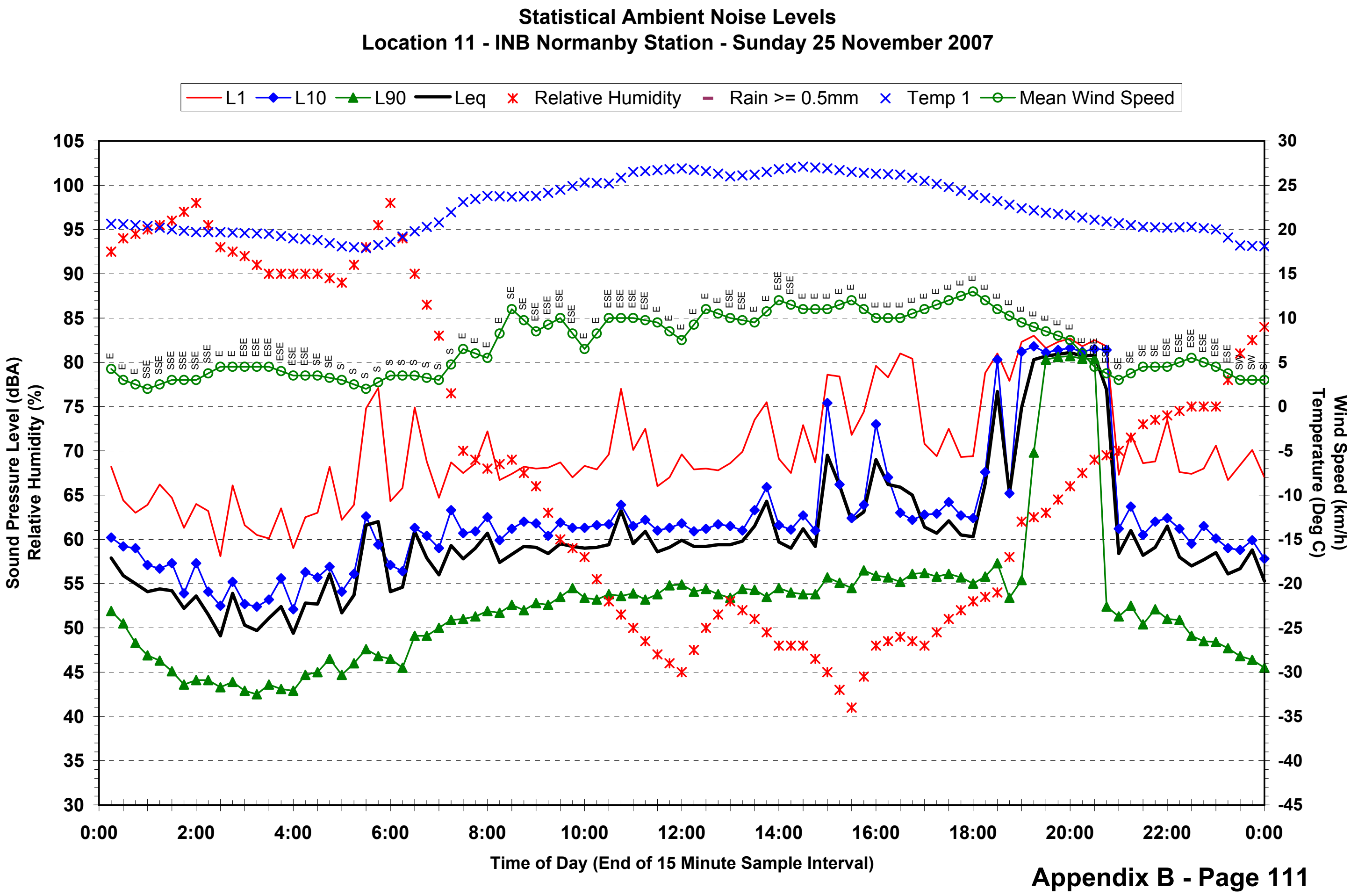
Heggies Report 20-1854



Appendix B - Page 110

Ambient Conditions

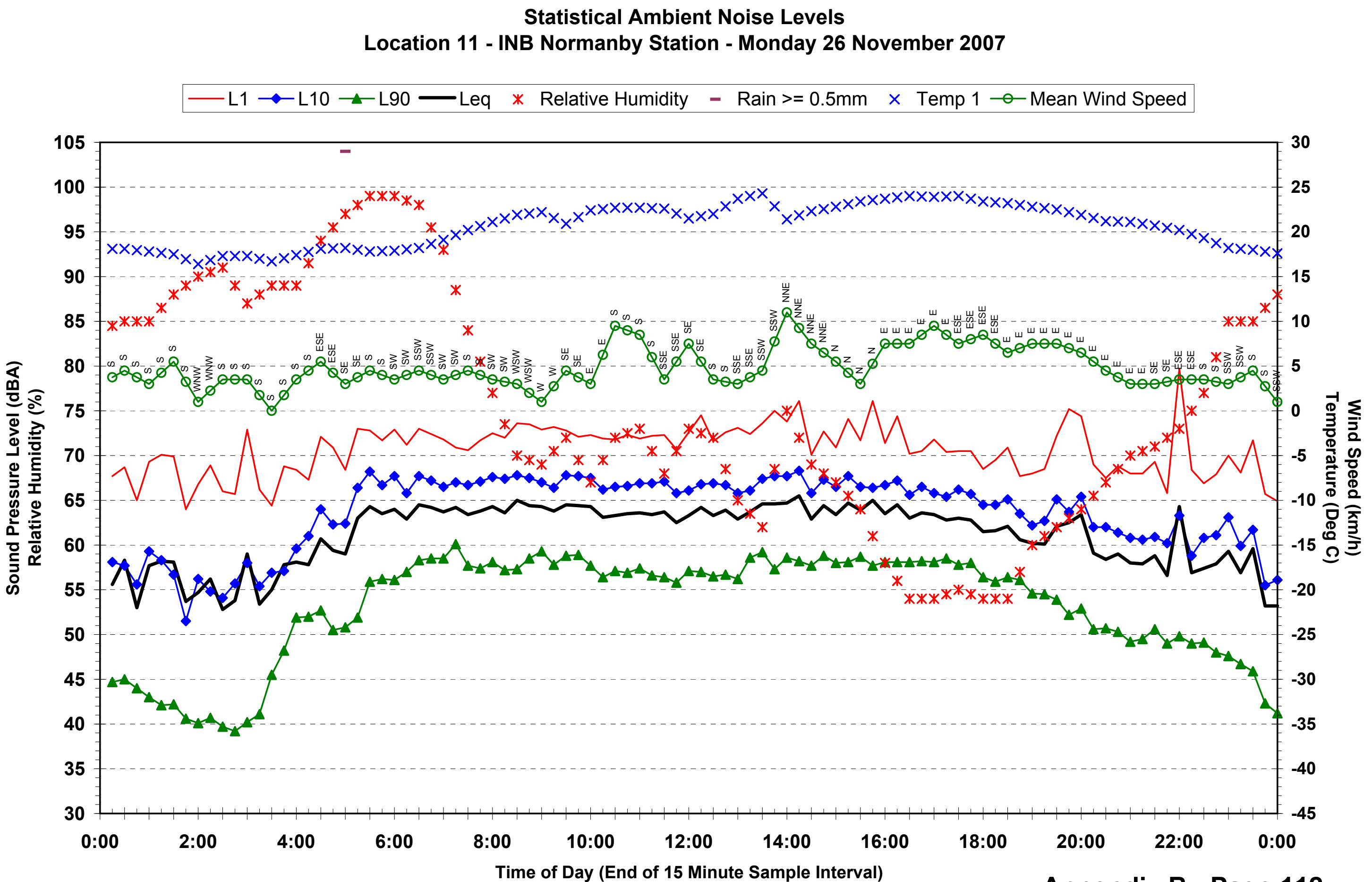
Heggies Report 20-1854



Appendix B - Page 111

Ambient Conditions

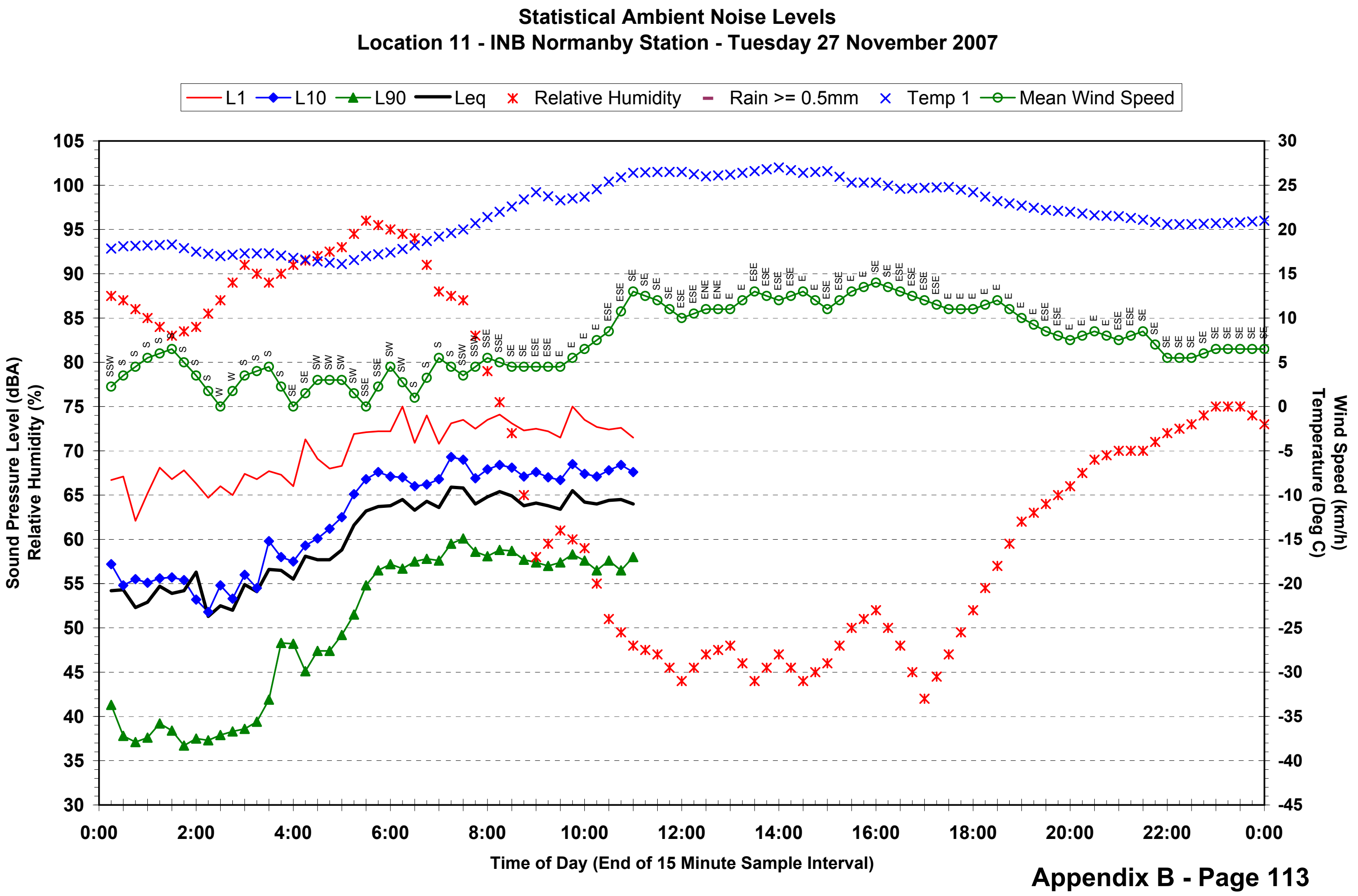
Heggies Report 20-1854



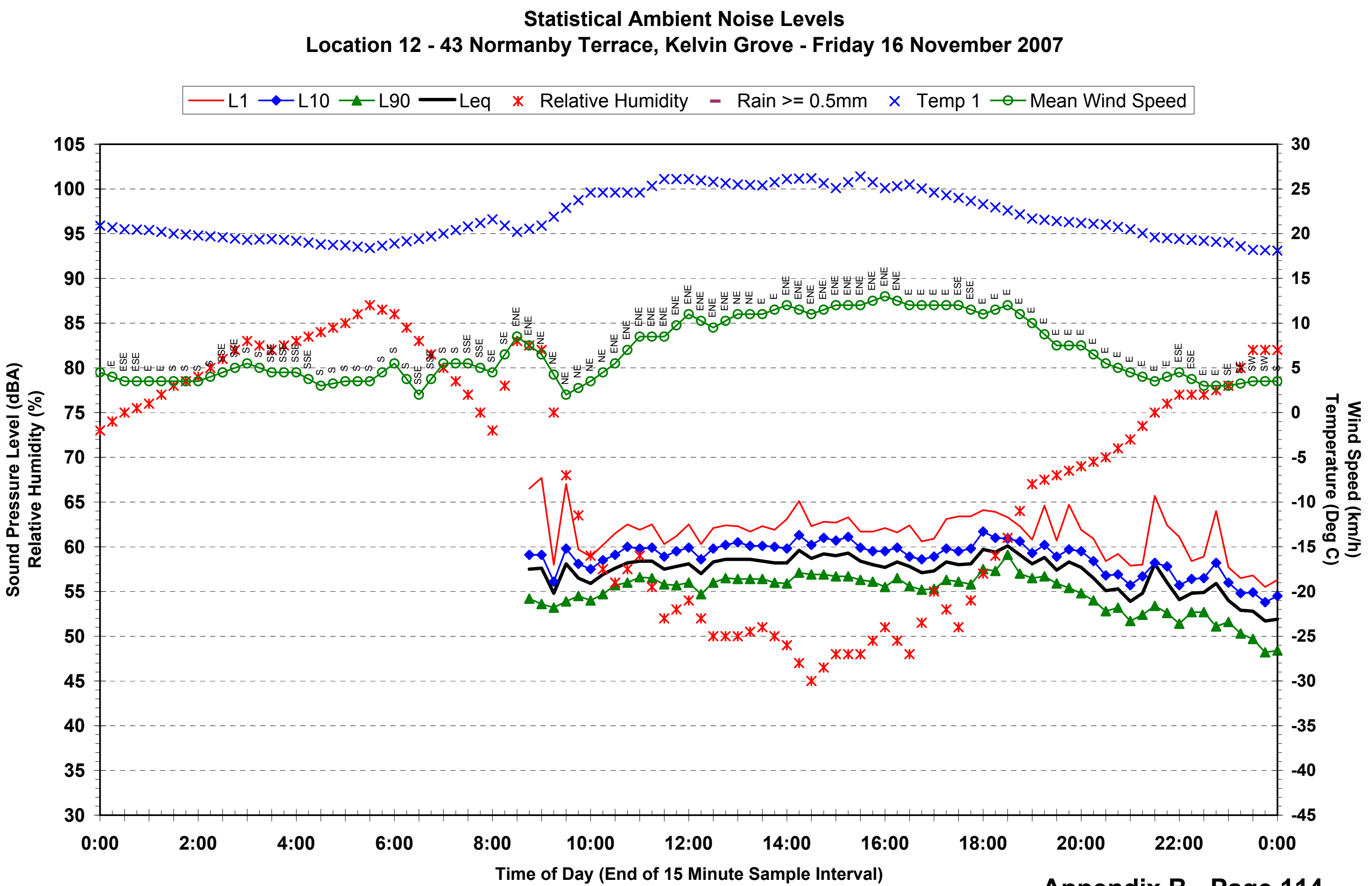
Appendix B - Page 112

Ambient Conditions

Heggies Report 20-1854

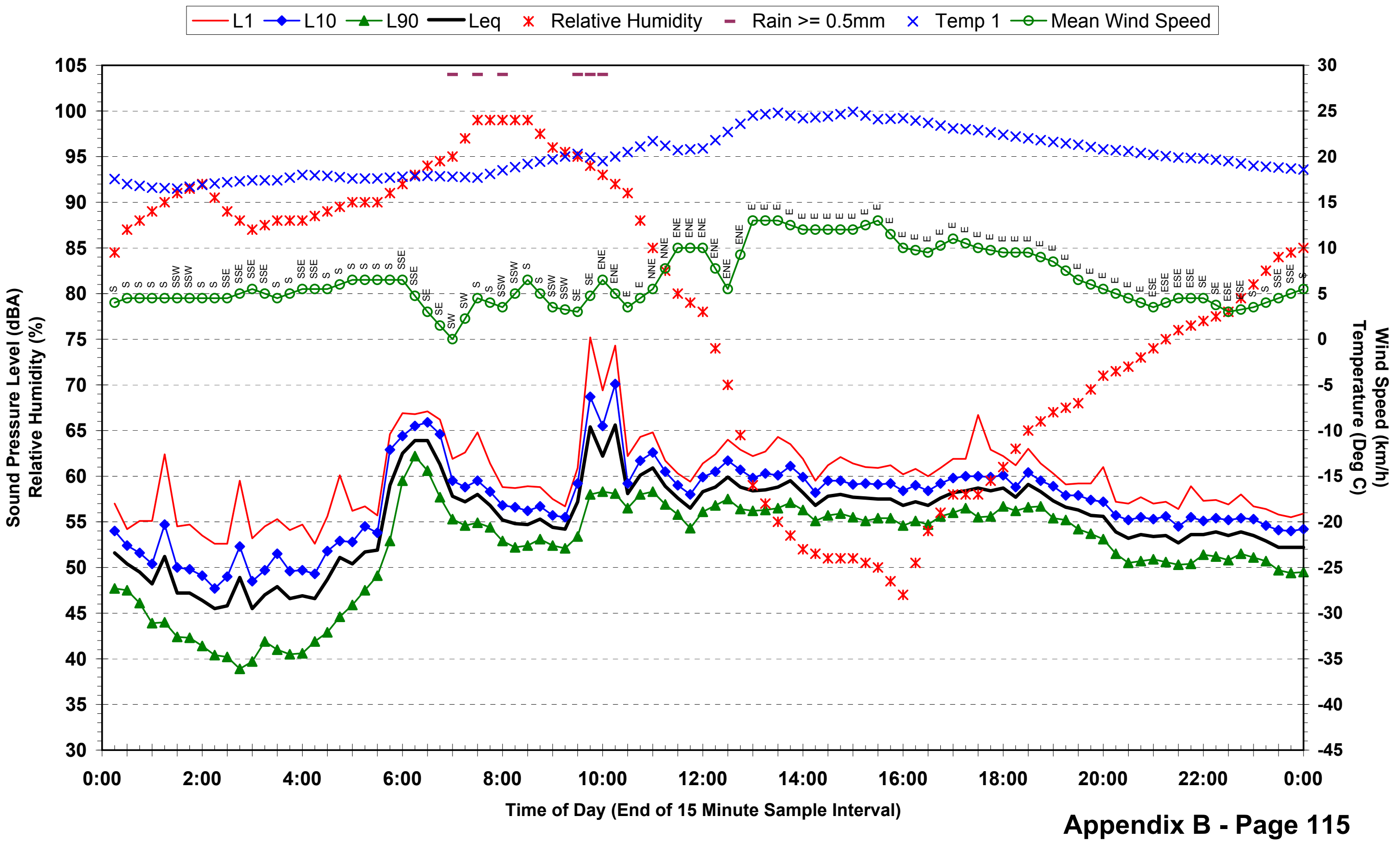


Appendix B - Page 113
Ambient Conditions
Heggies Report 20-1854



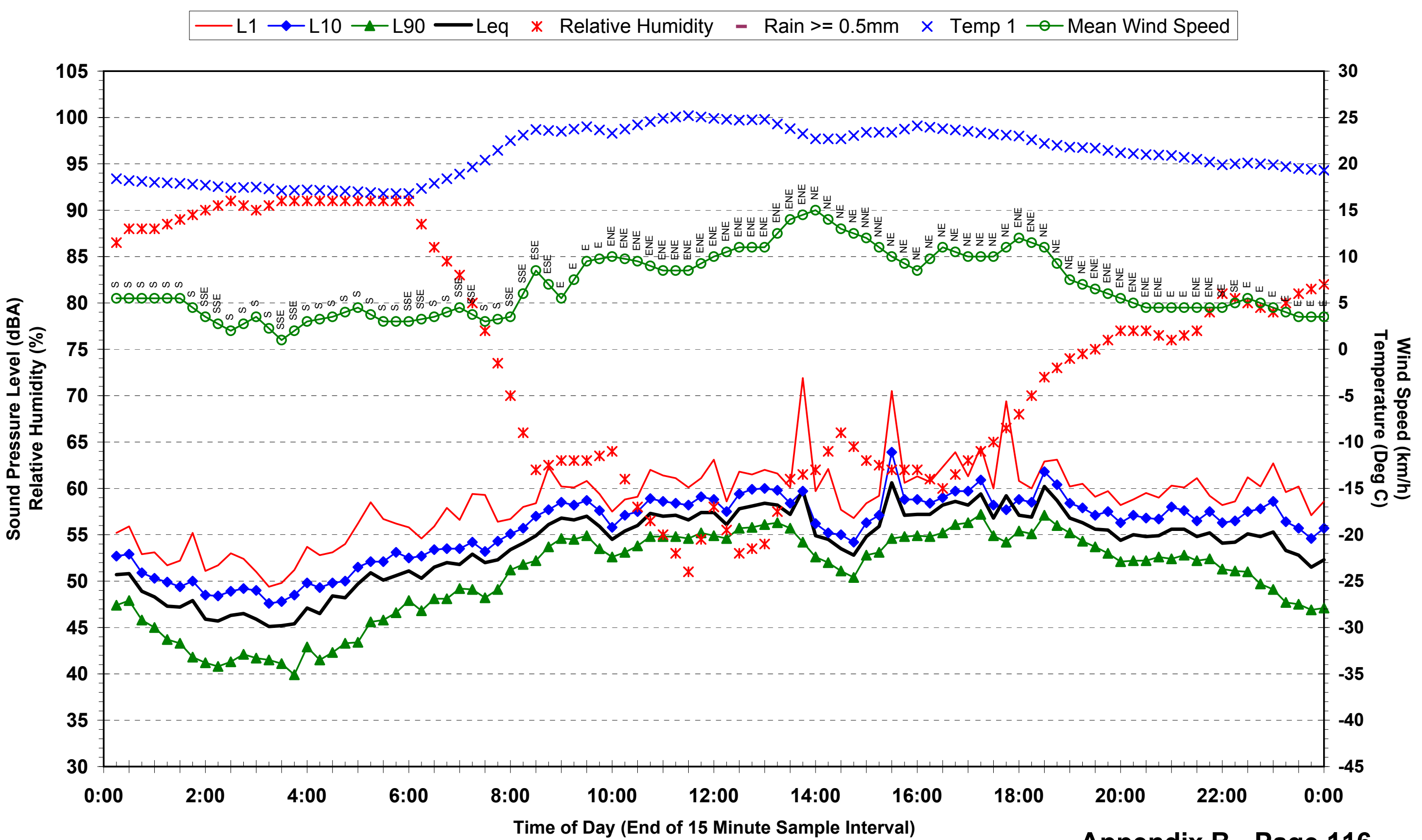
Appendix B - Page 114
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Saturday 17 November 2007



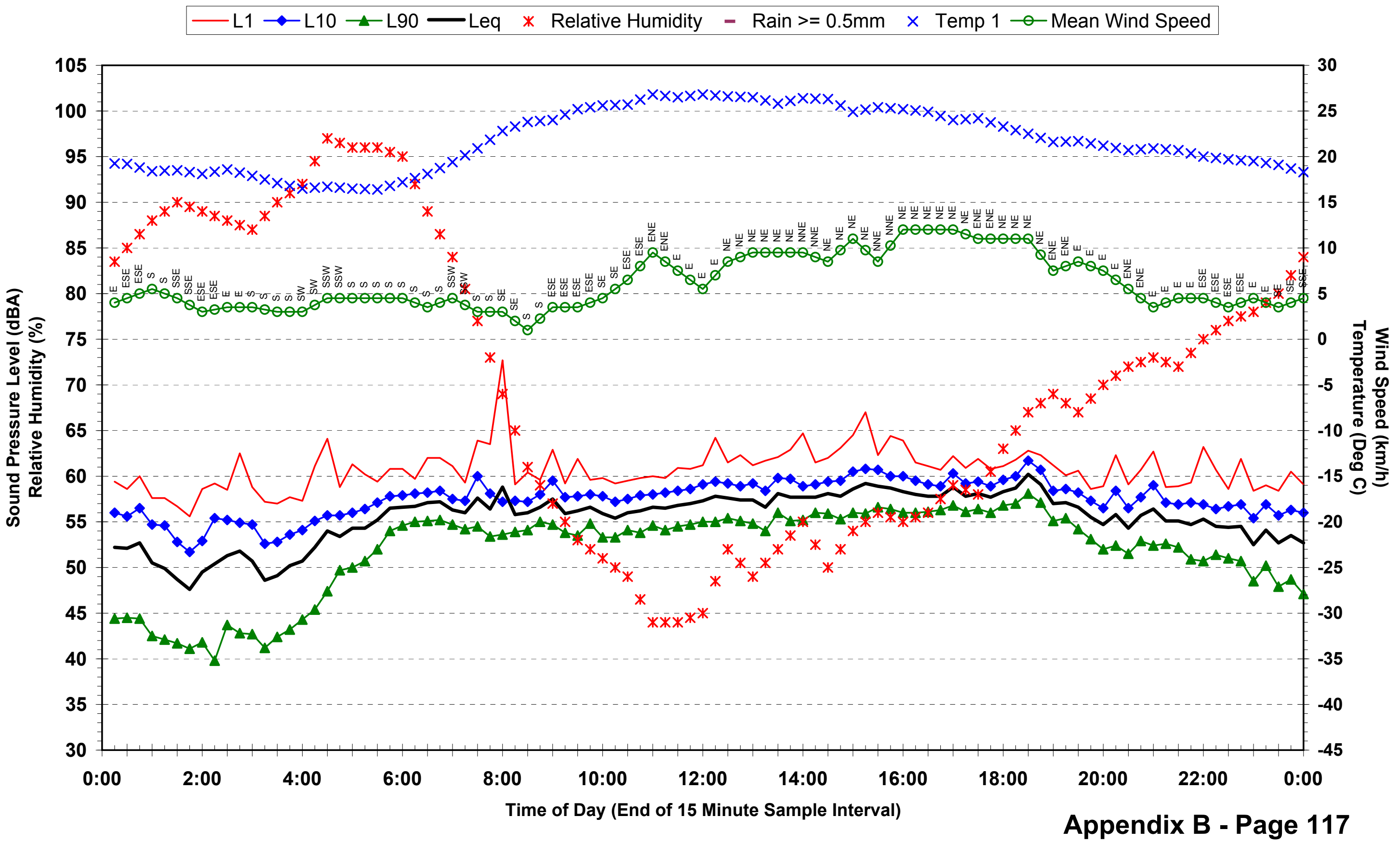
Appendix B - Page 115
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Sunday 18 November 2007



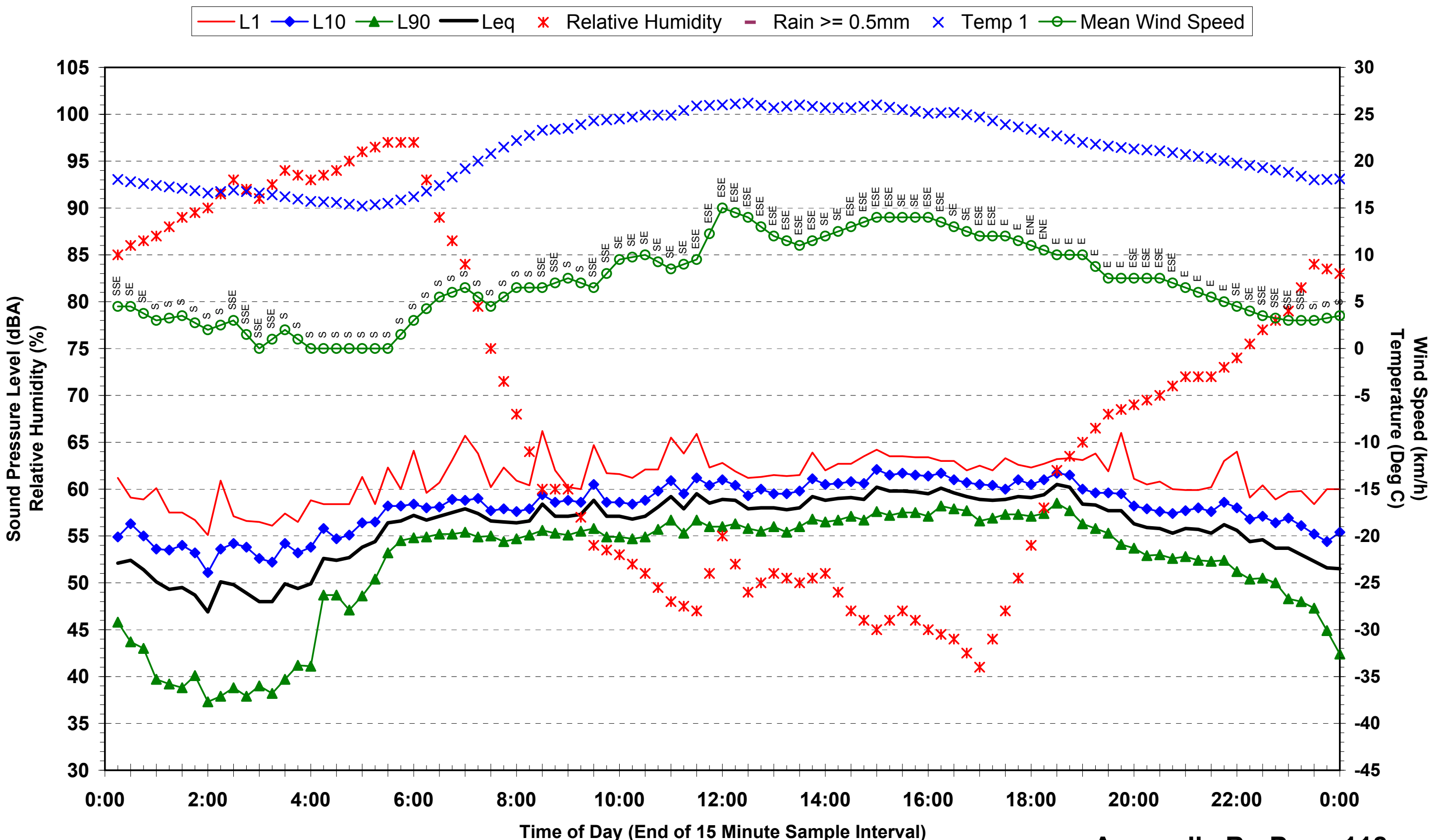
Appendix B - Page 116
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Monday 19 November 2007



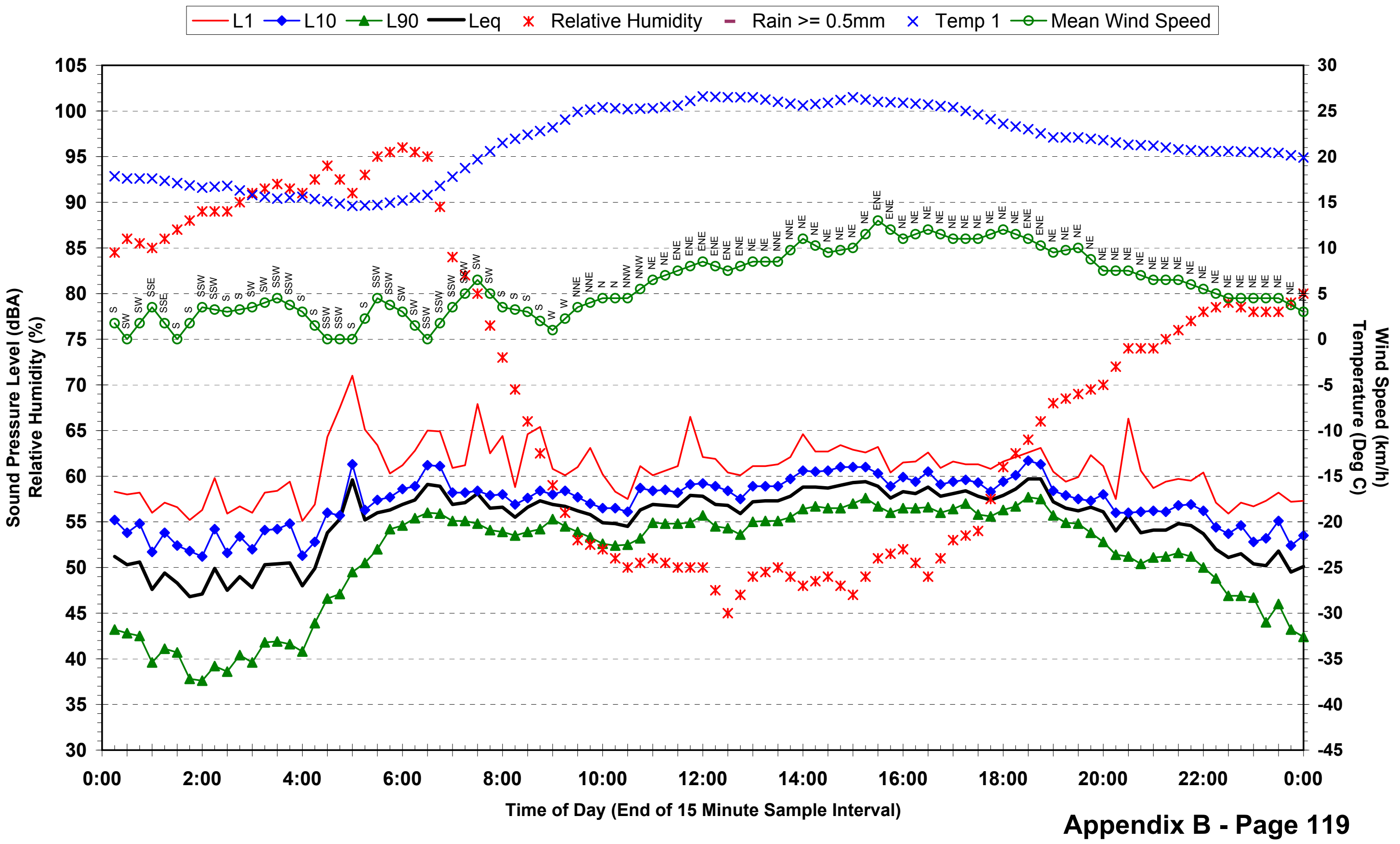
Appendix B - Page 117
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Tuesday 20 November 2007



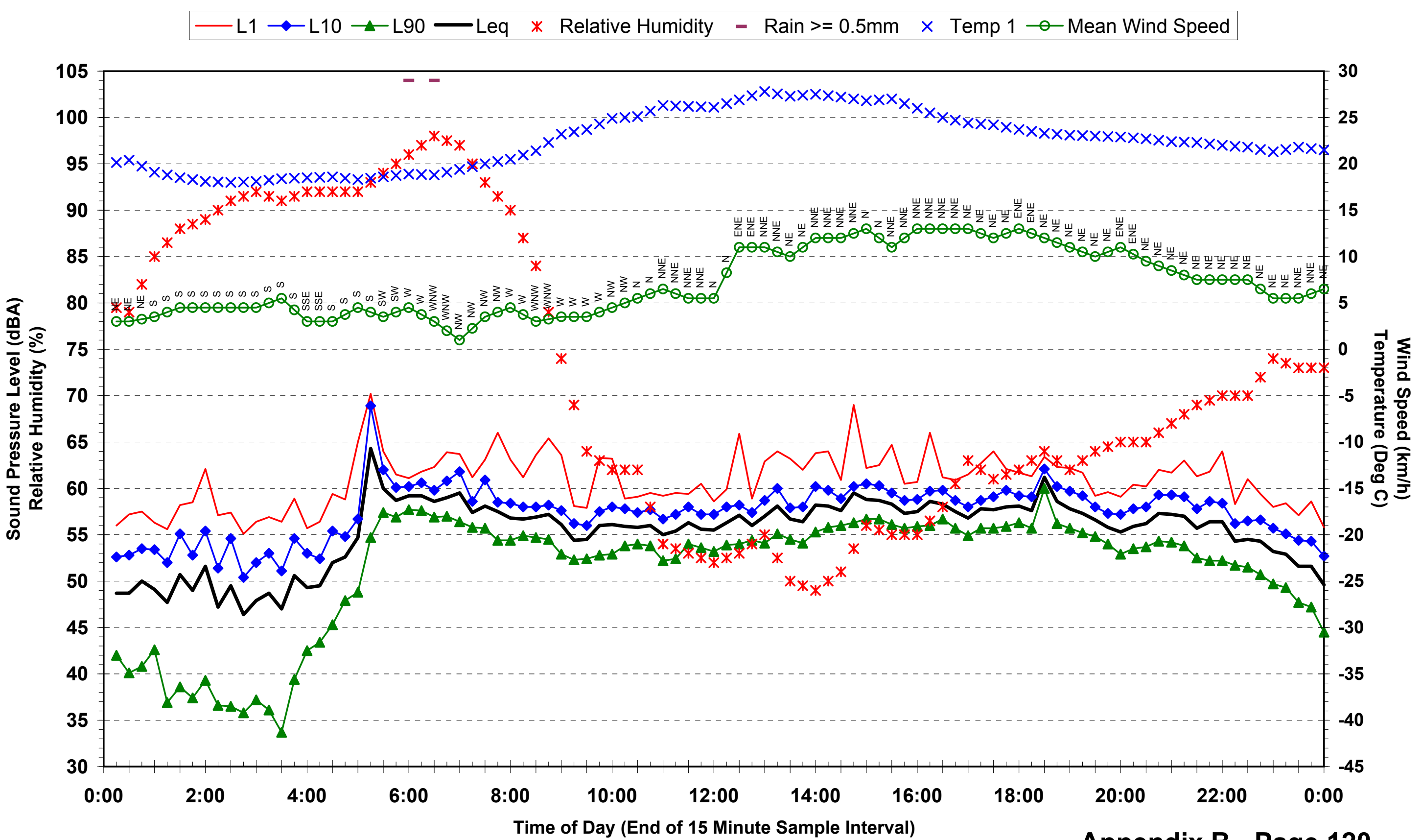
Appendix B - Page 118
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Wednesday 21 November 2007



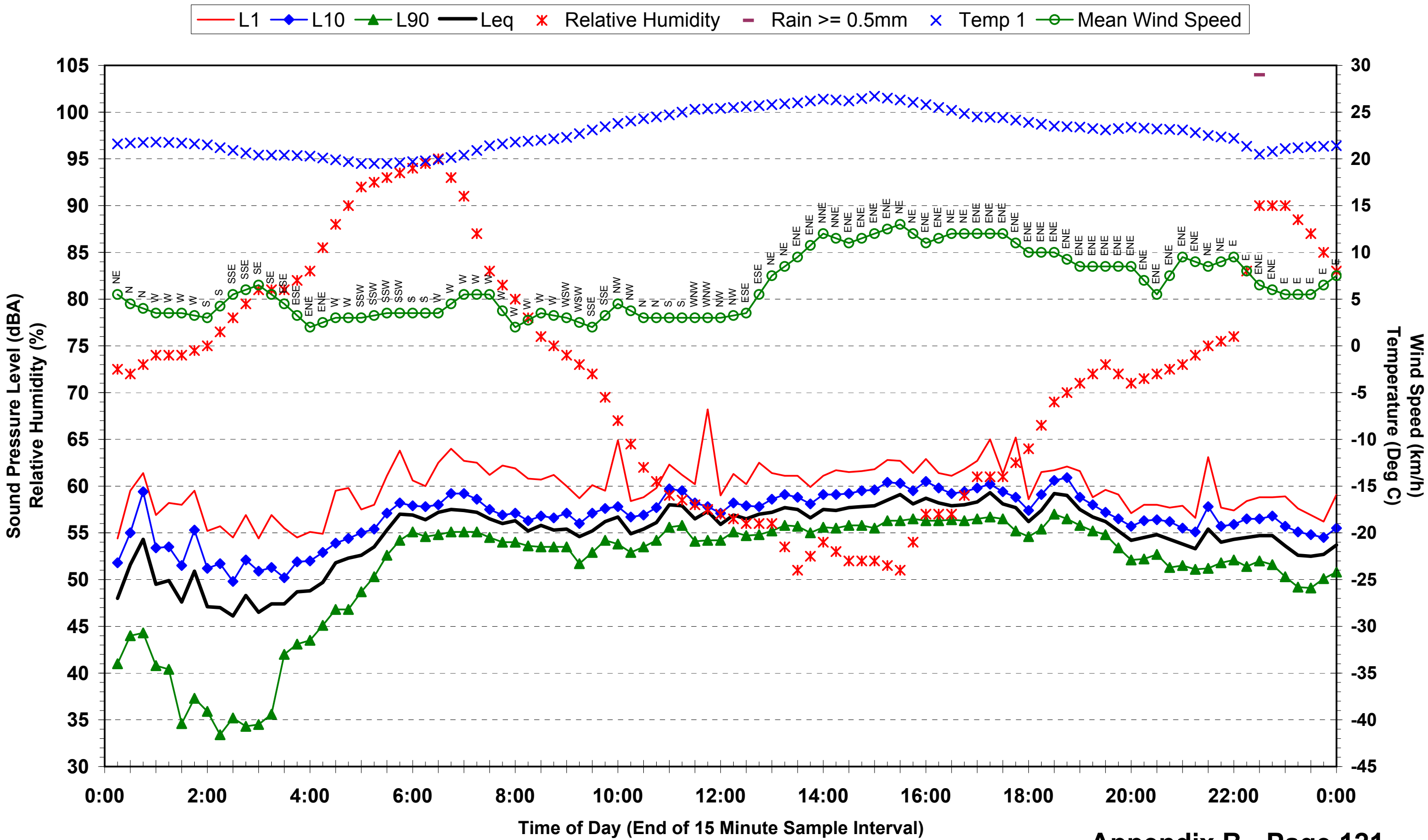
Appendix B - Page 119
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Thursday 22 November 2007



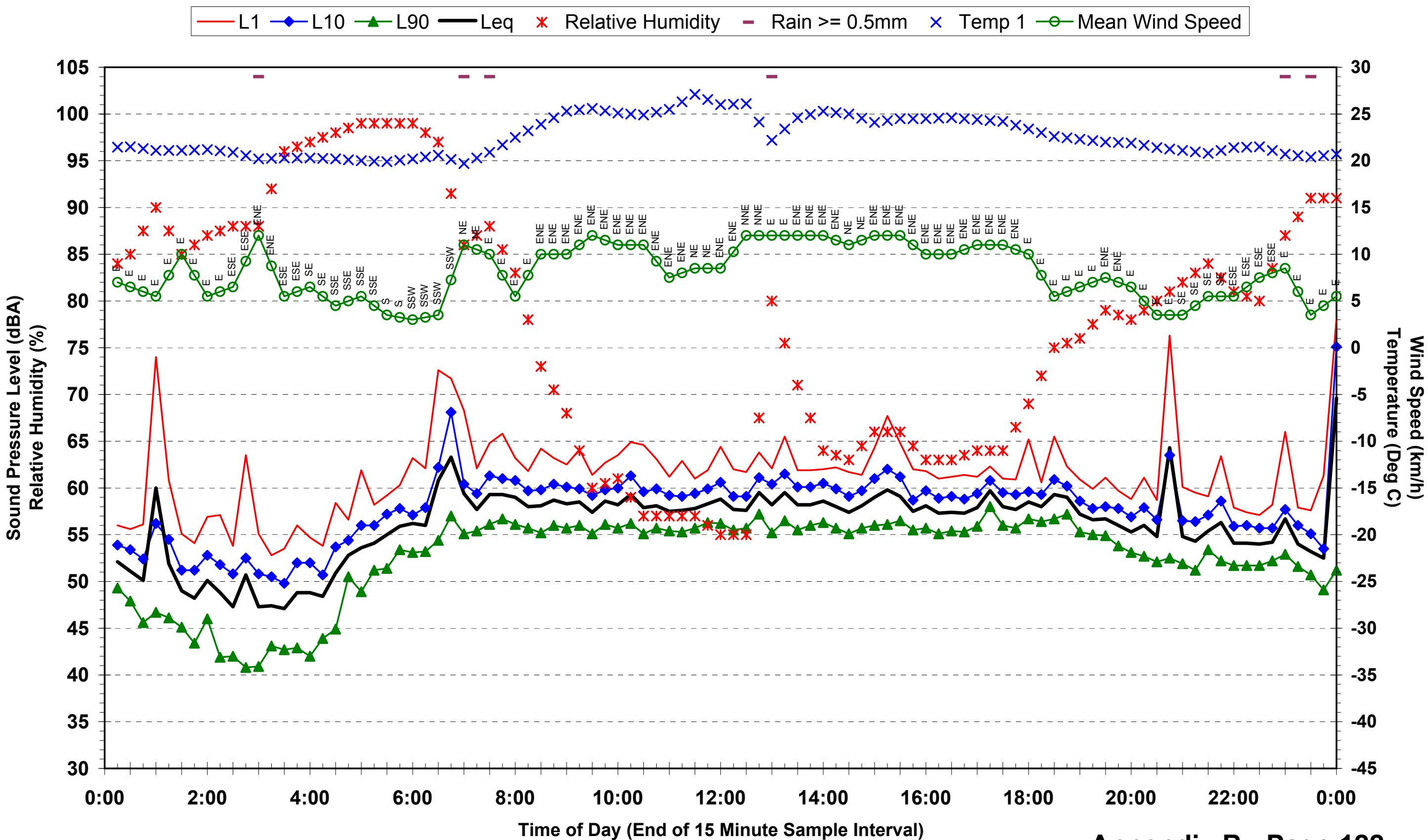
Appendix B - Page 120
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Friday 23 November 2007



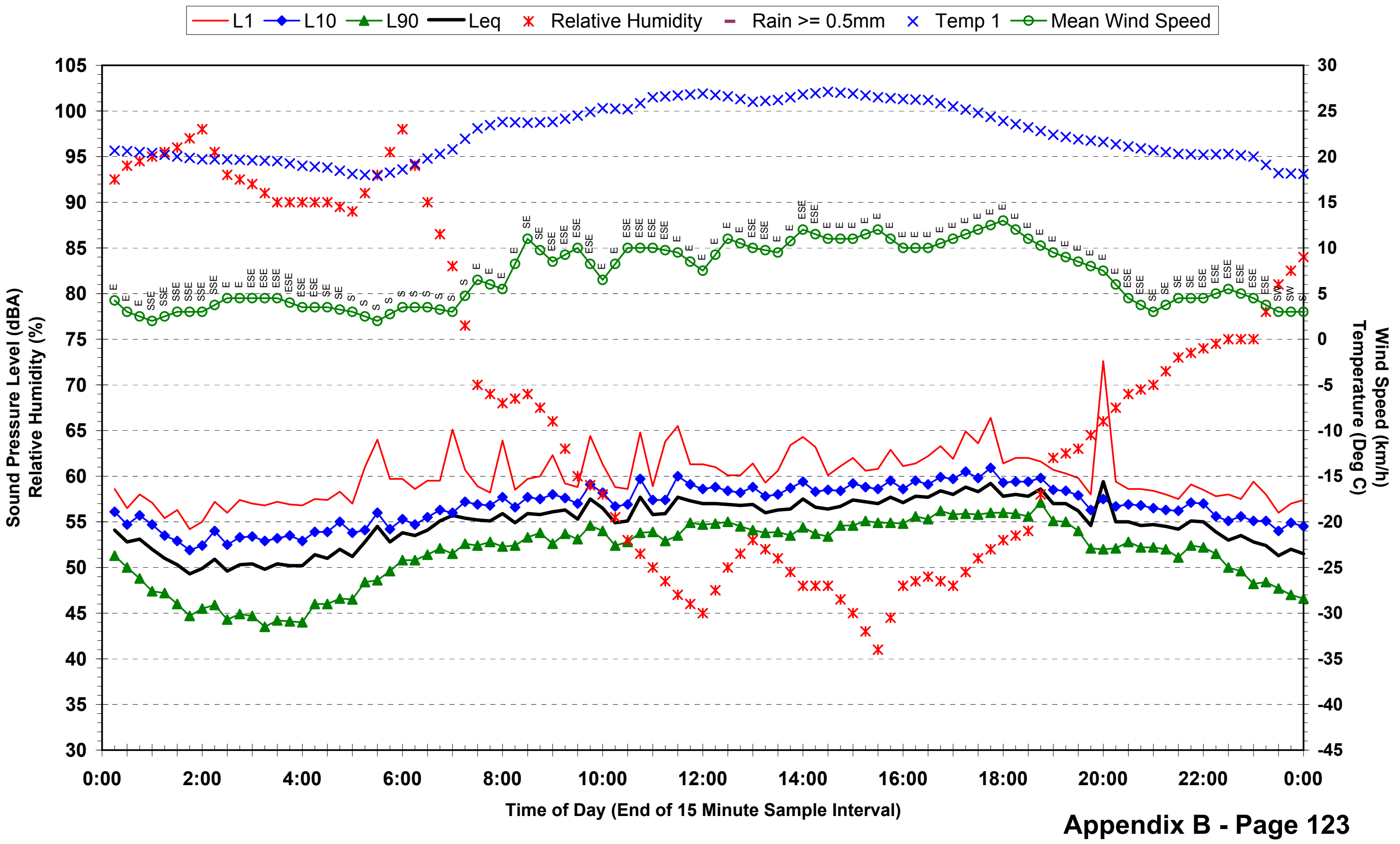
Appendix B - Page 121
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Saturday 24 November 2007



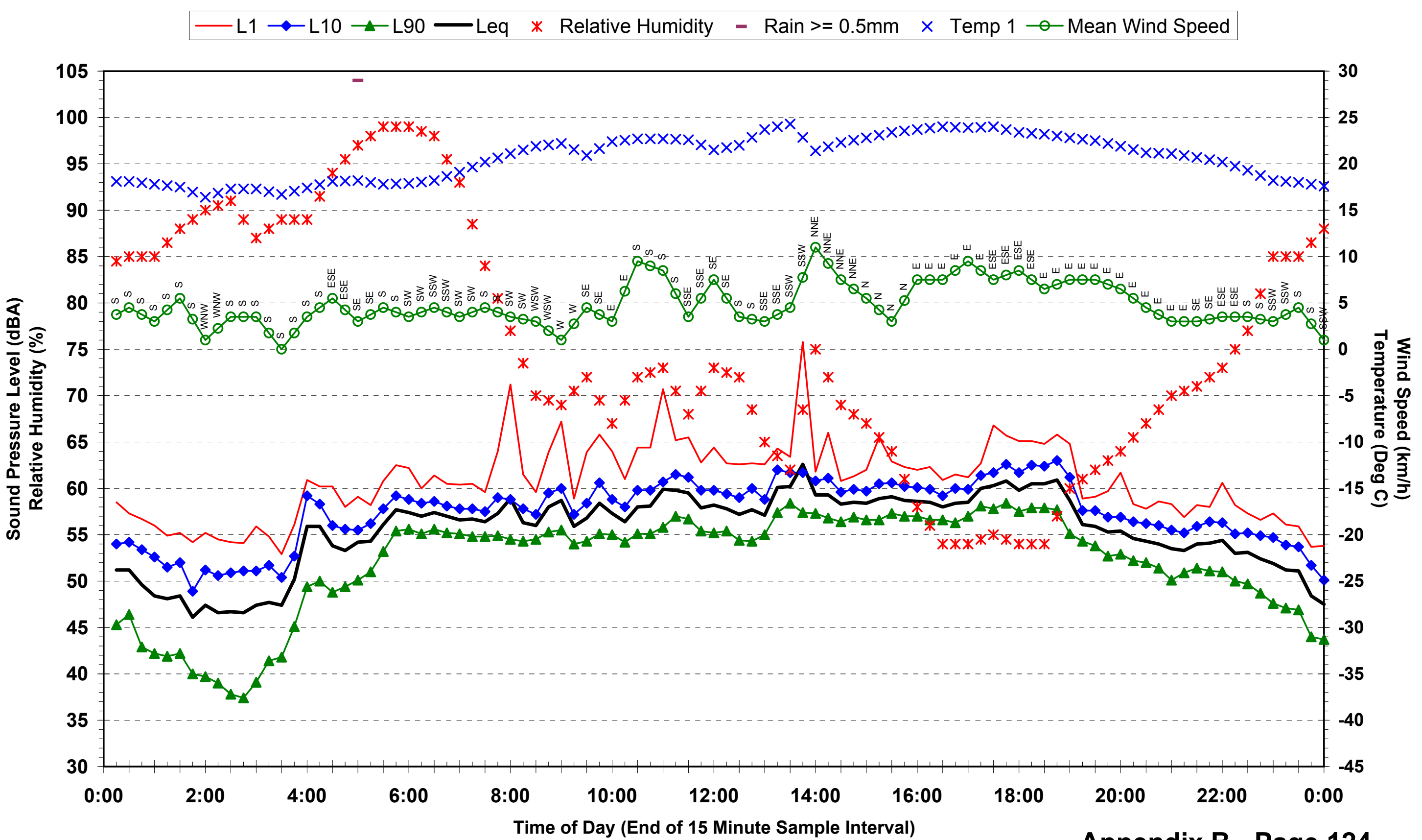
Appendix B - Page 122
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Sunday 25 November 2007



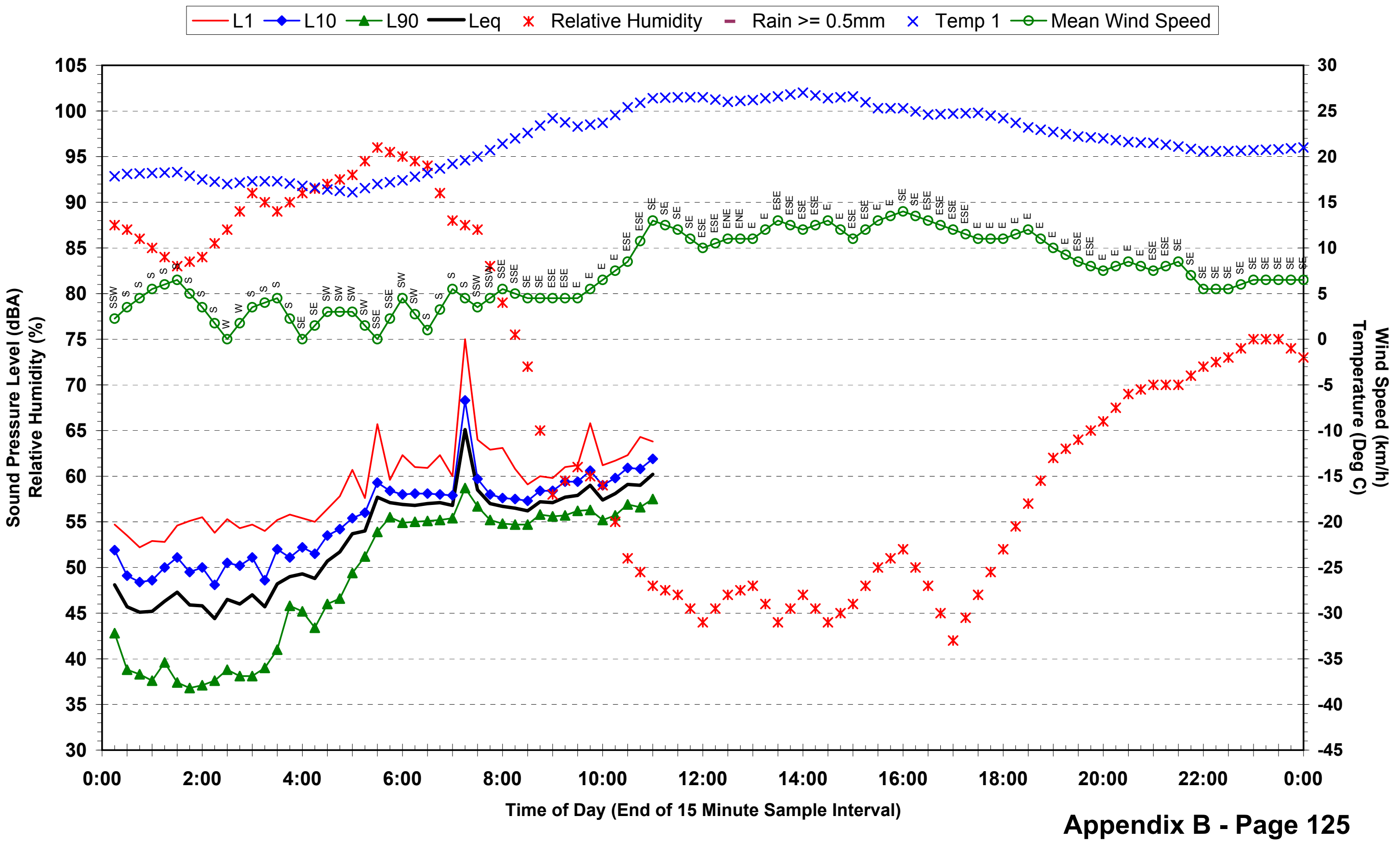
Appendix B - Page 123
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Monday 26 November 2007



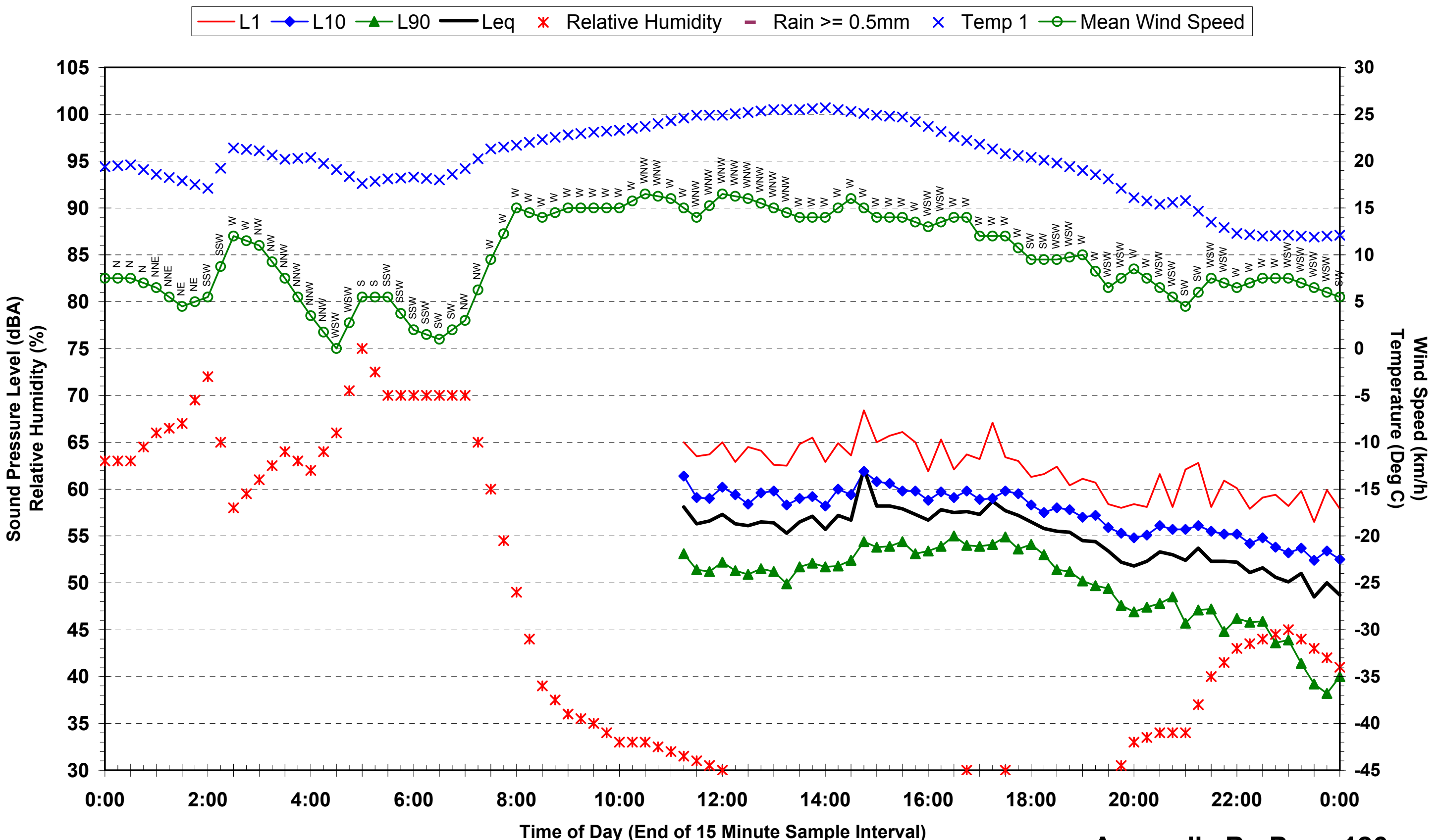
Appendix B - Page 124
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 12 - 43 Normanby Terrace, Kelvin Grove - Tuesday 27 November 2007



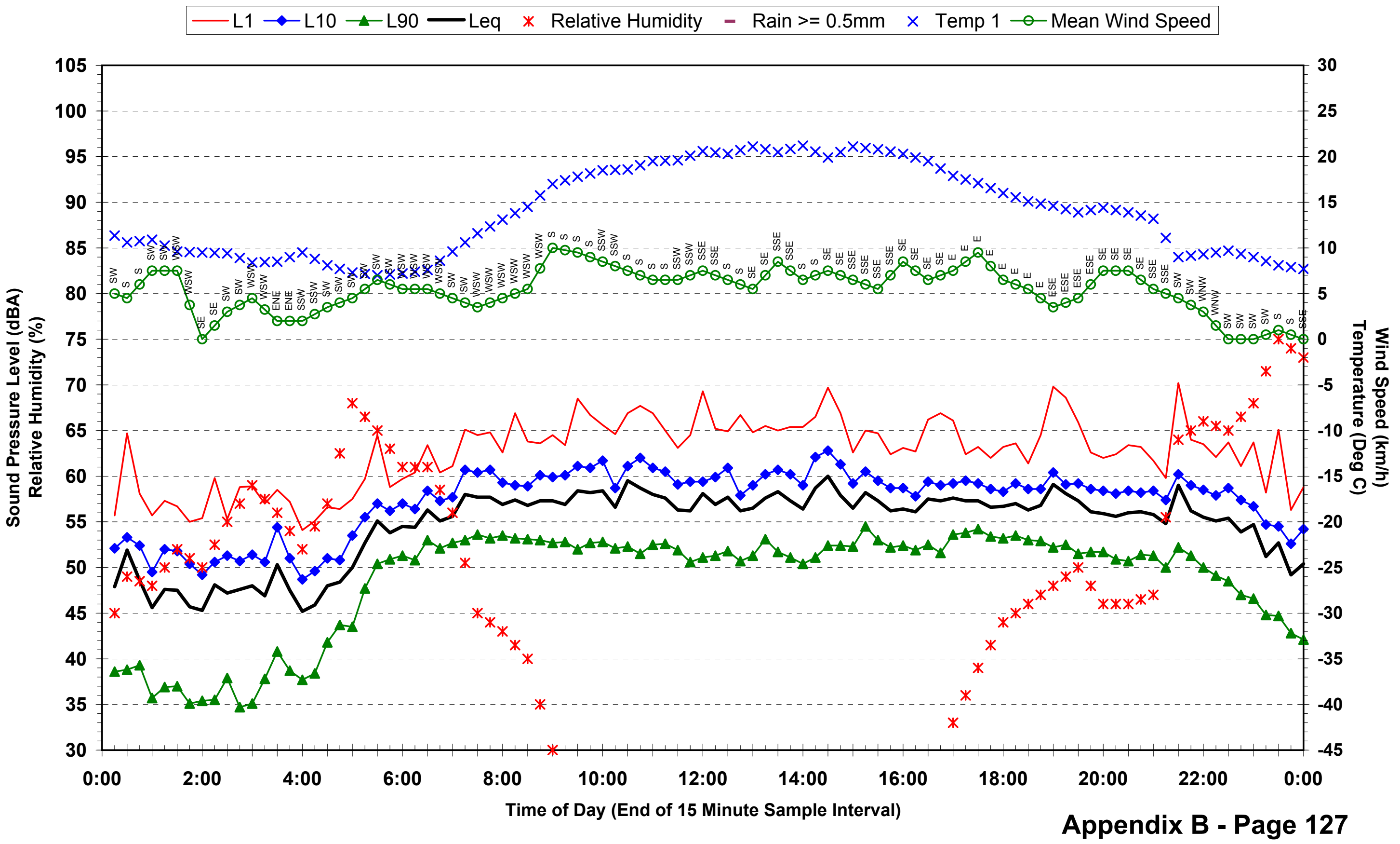
Appendix B - Page 125
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Monday 28 April 2008



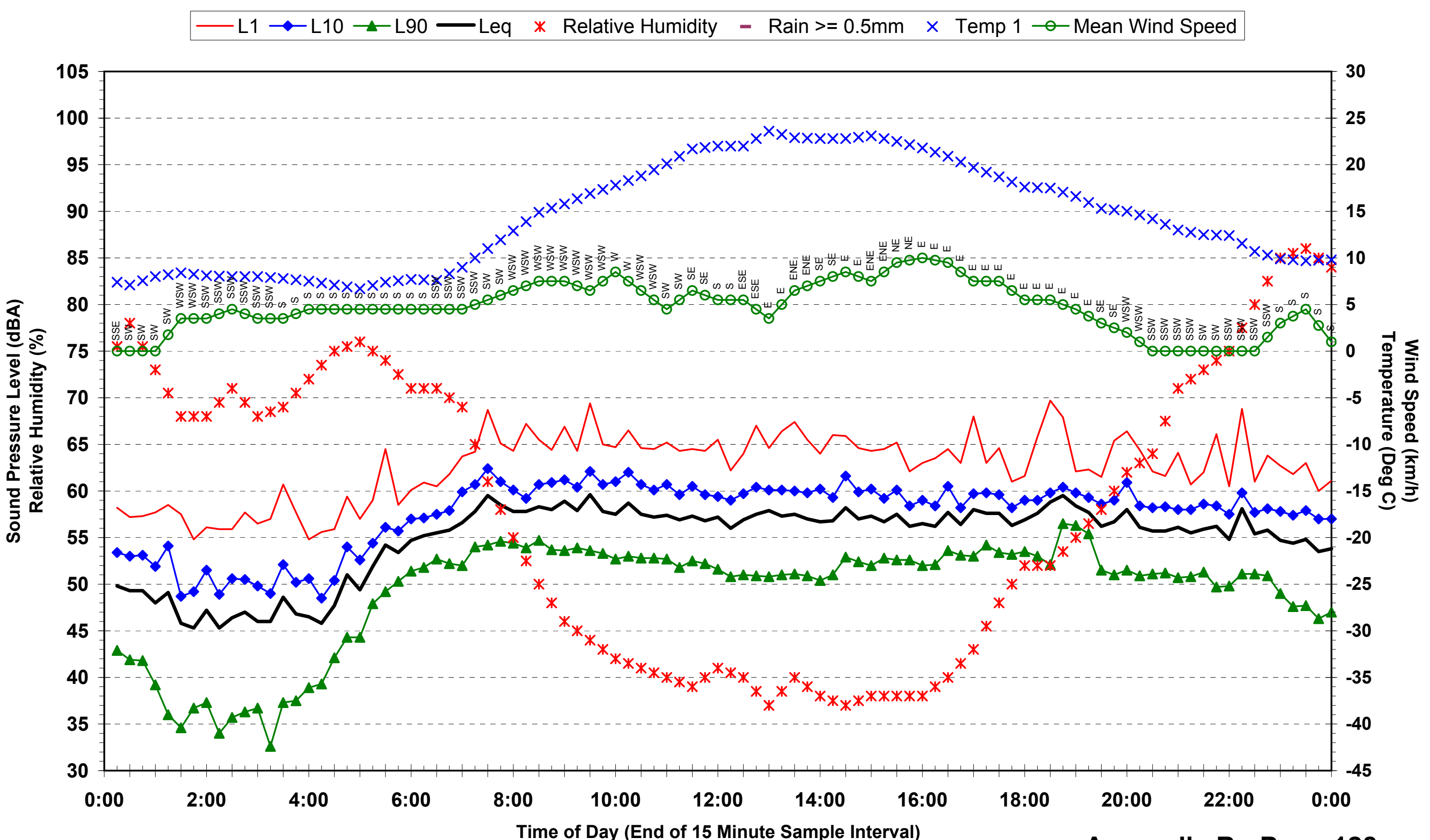
Appendix B - Page 126
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Tuesday 29 April 2008



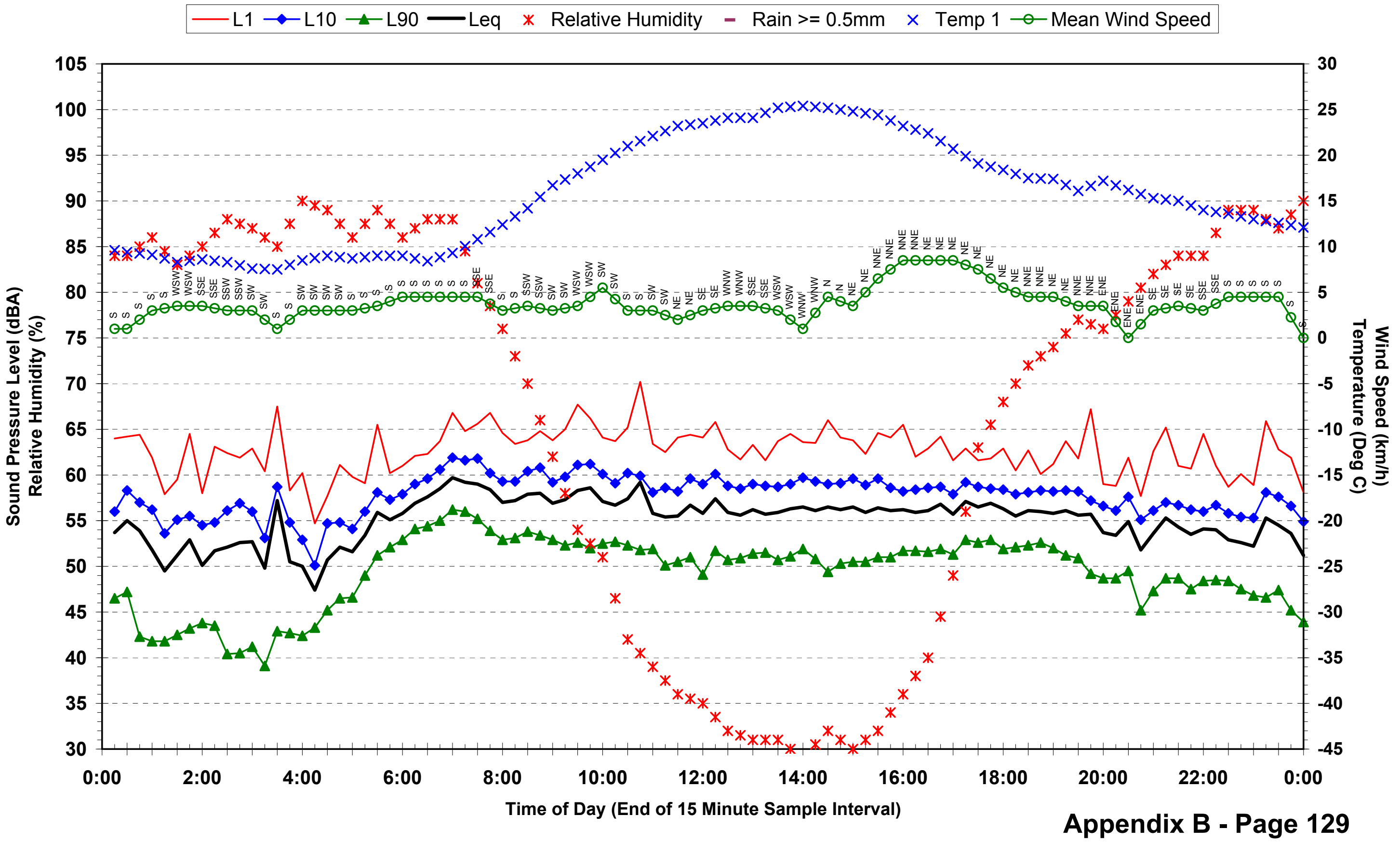
Appendix B - Page 127
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Wednesday 30 April 2008



Appendix B - Page 128
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Thursday 1 May 2008

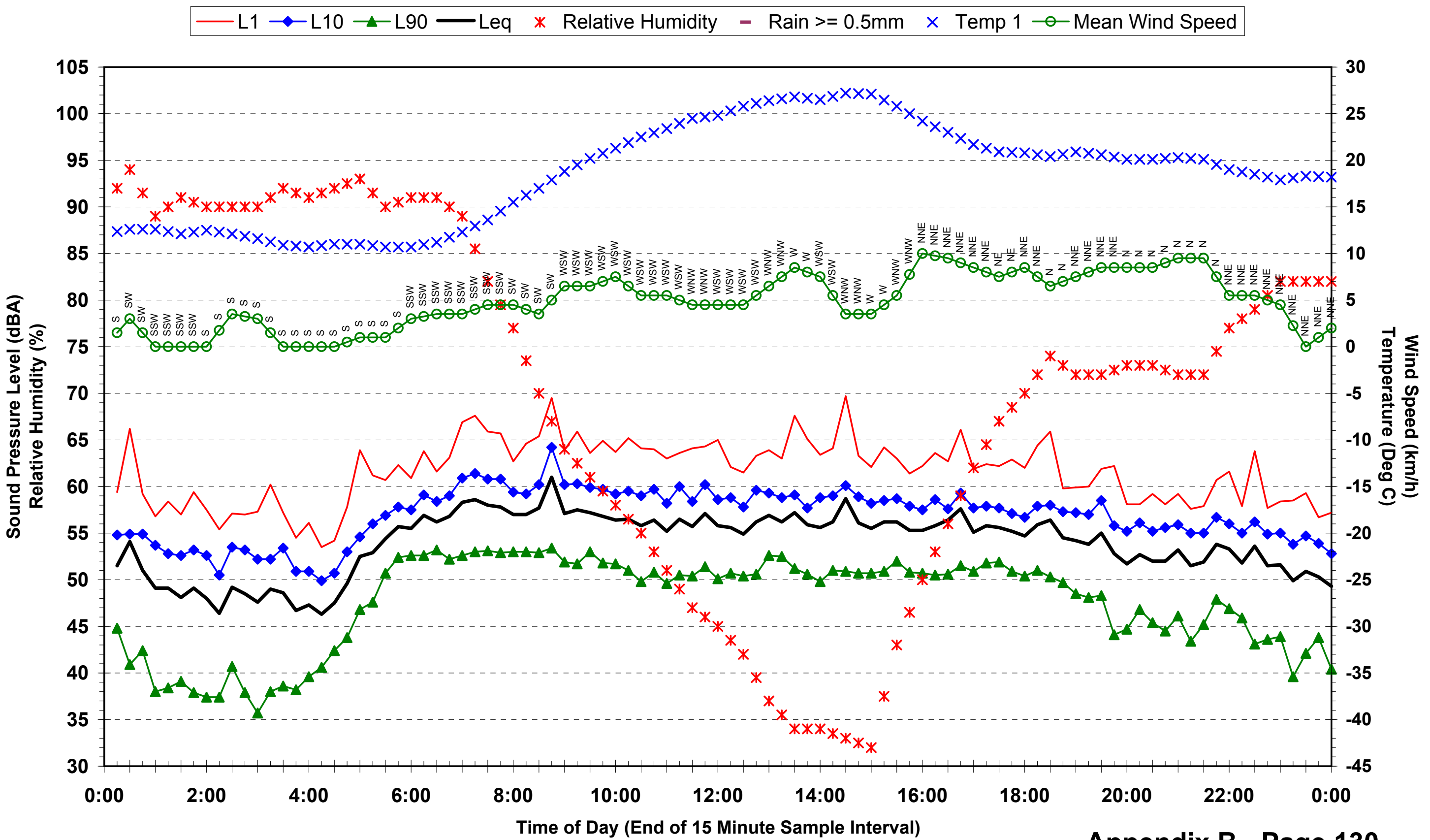


Appendix B - Page 129

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Friday 2 May 2008

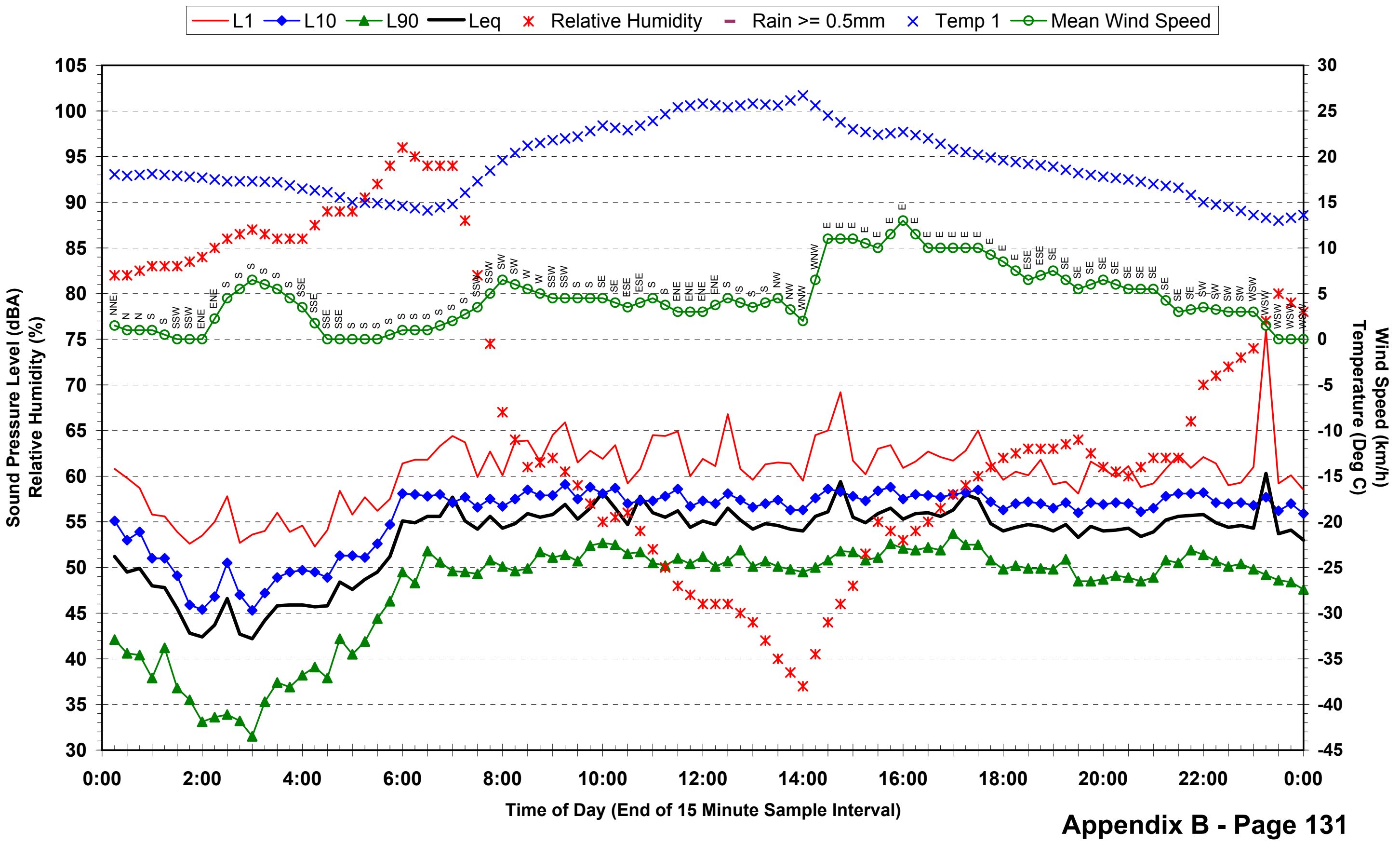


Appendix B - Page 130

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Saturday 3 May 2008

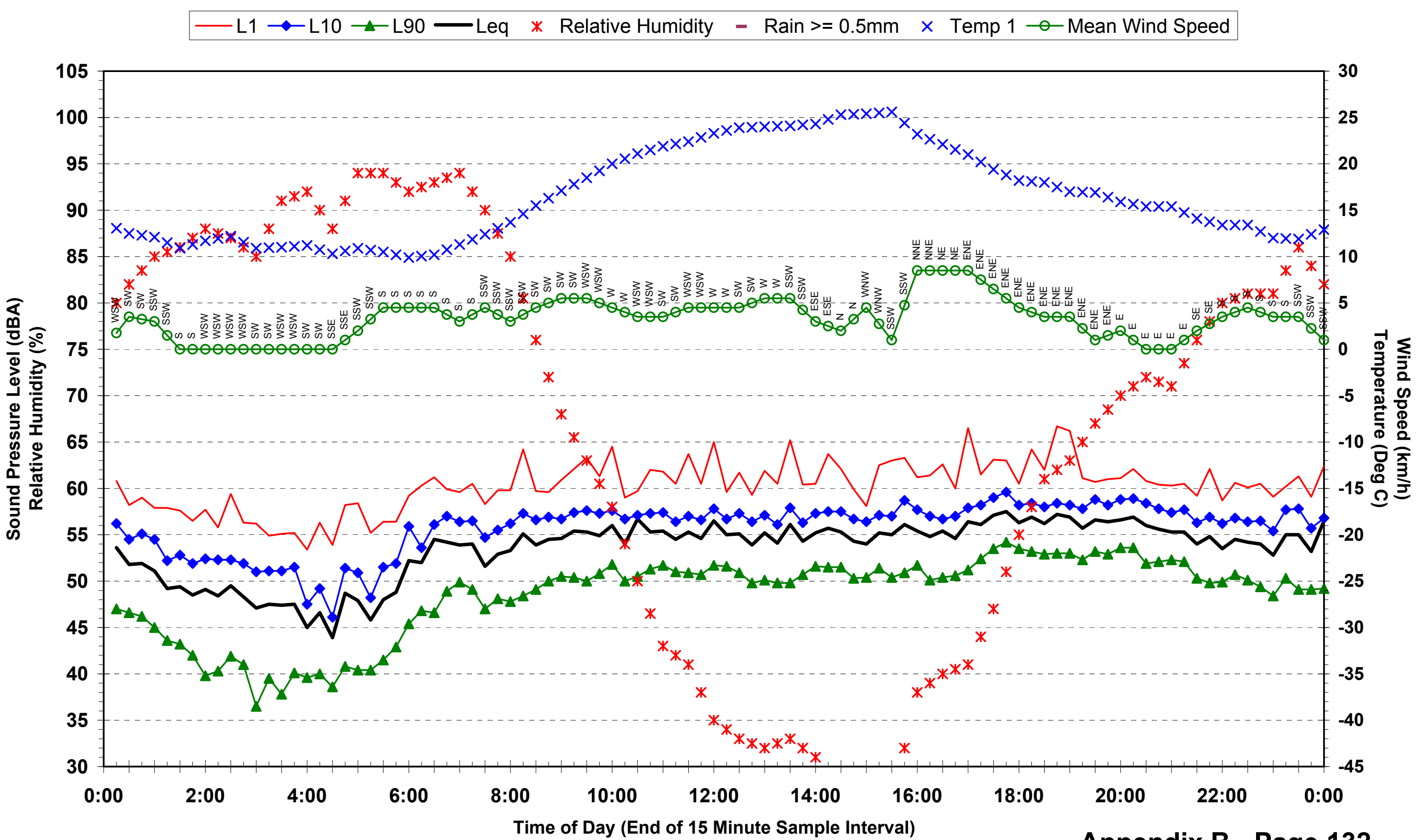


Appendix B - Page 131

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Sunday 4 May 2008

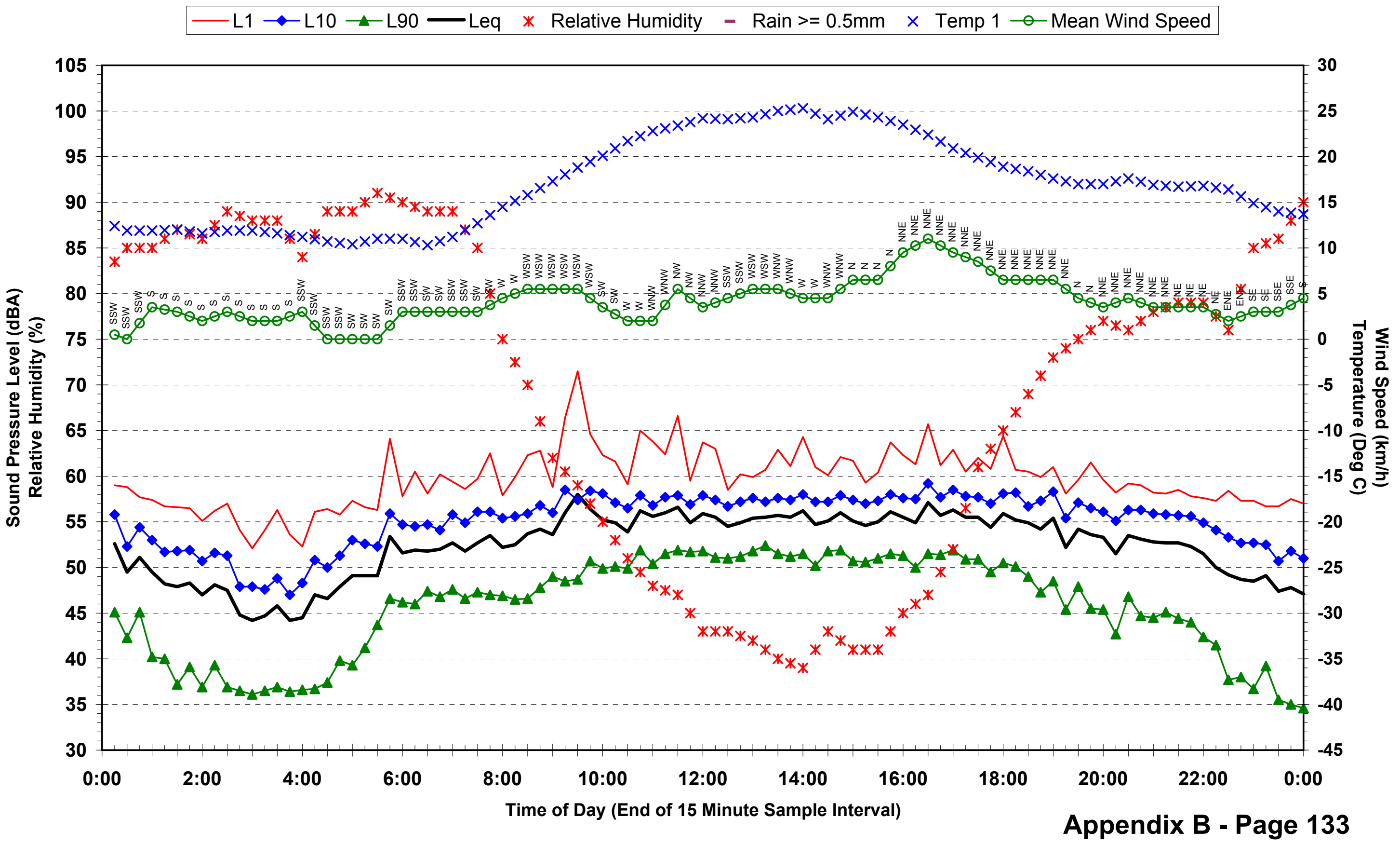


Appendix B - Page 132

Ambient Conditions

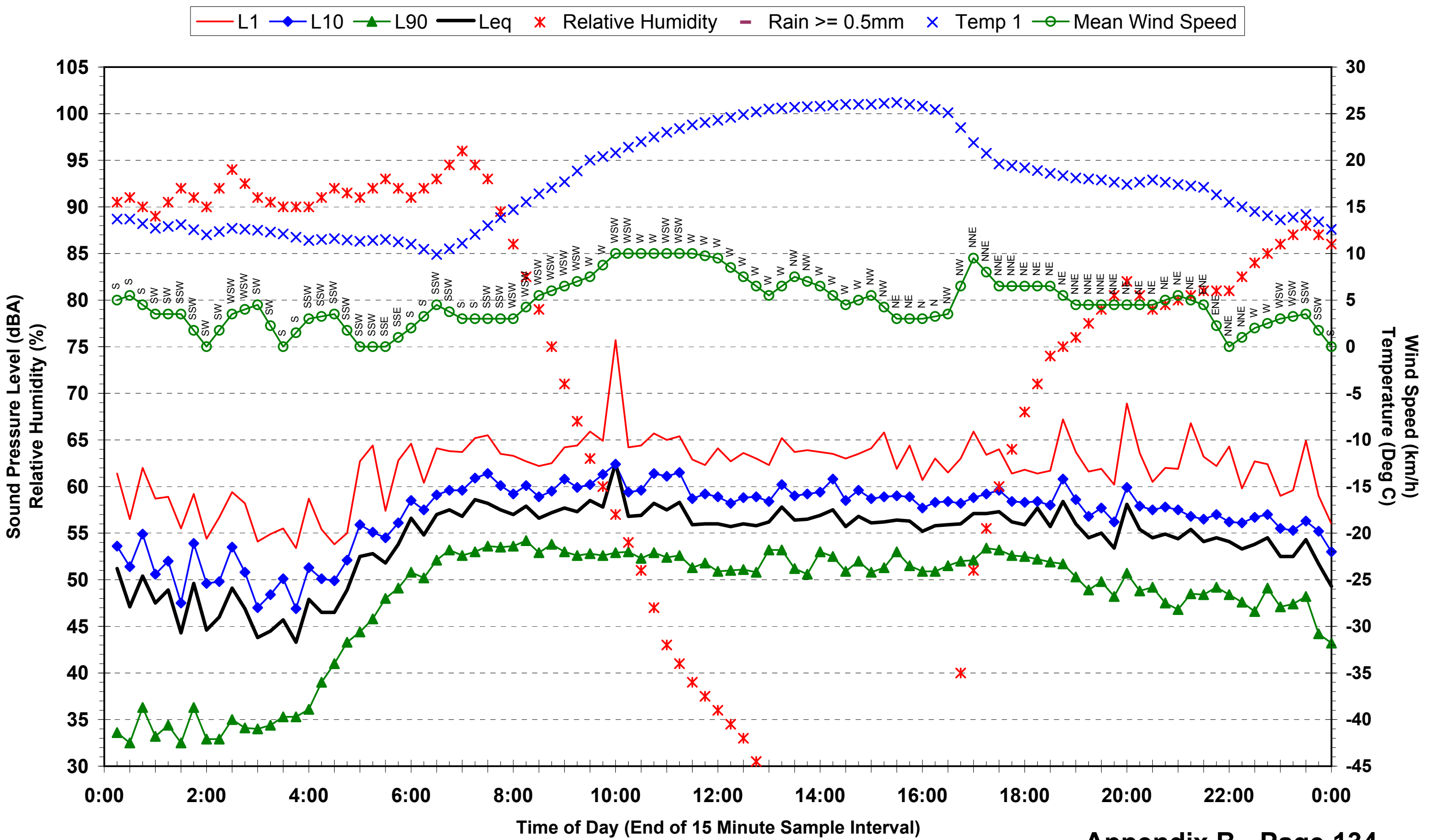
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Monday 5 May 2008



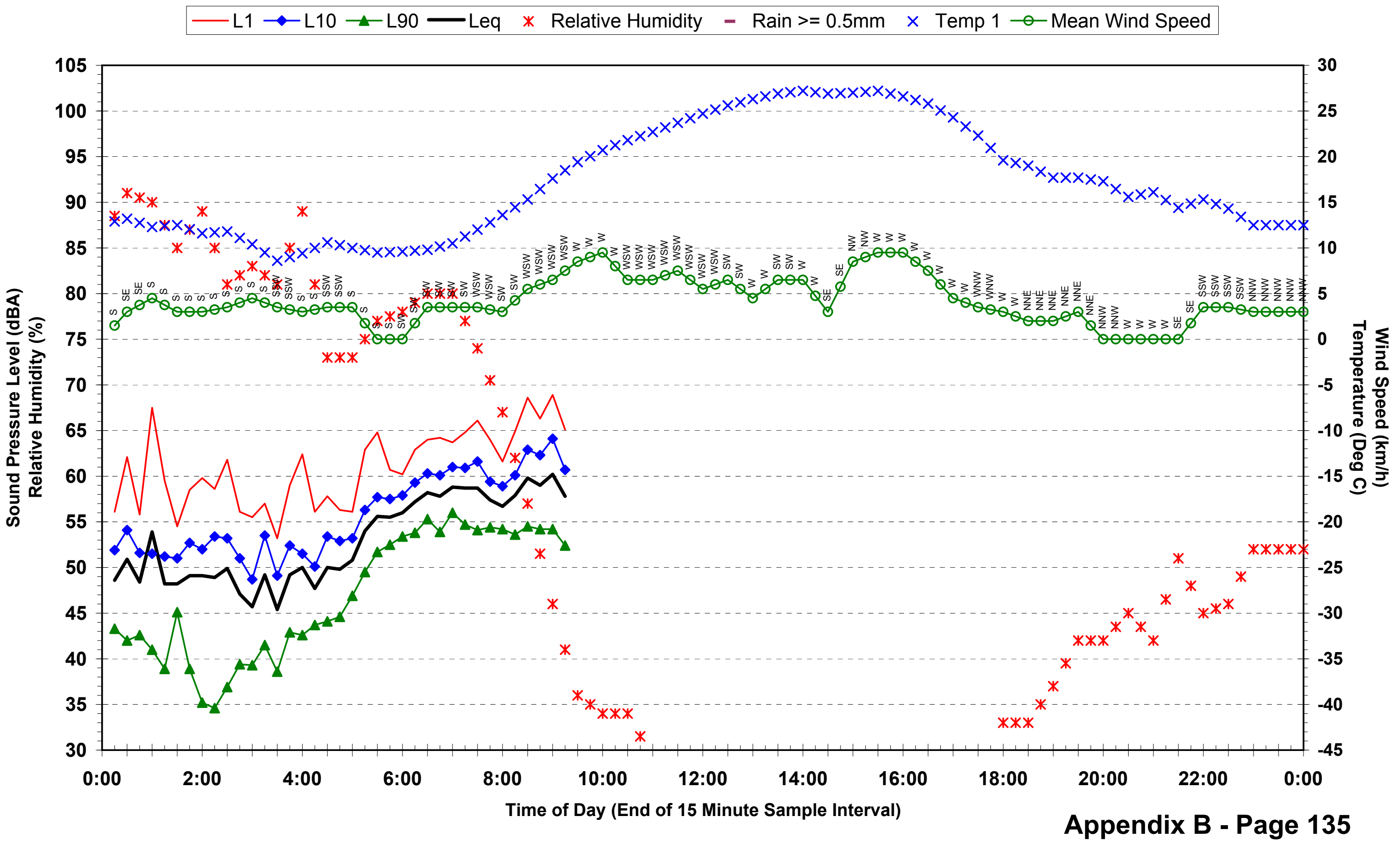
Appendix B - Page 133
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Tuesday 6 May 2008

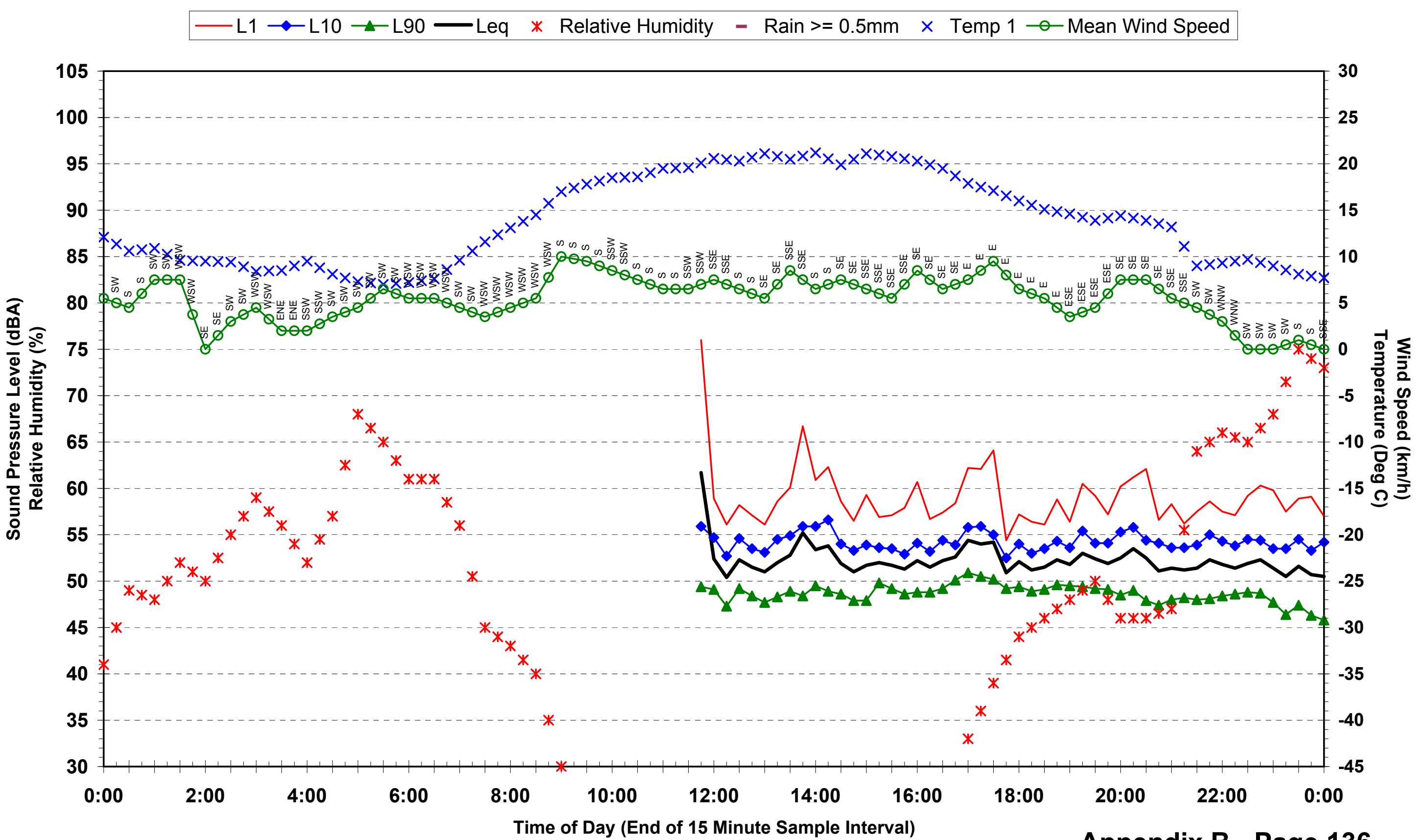


Appendix B - Page 134
Ambient Conditions
Heggies Report 20-1854

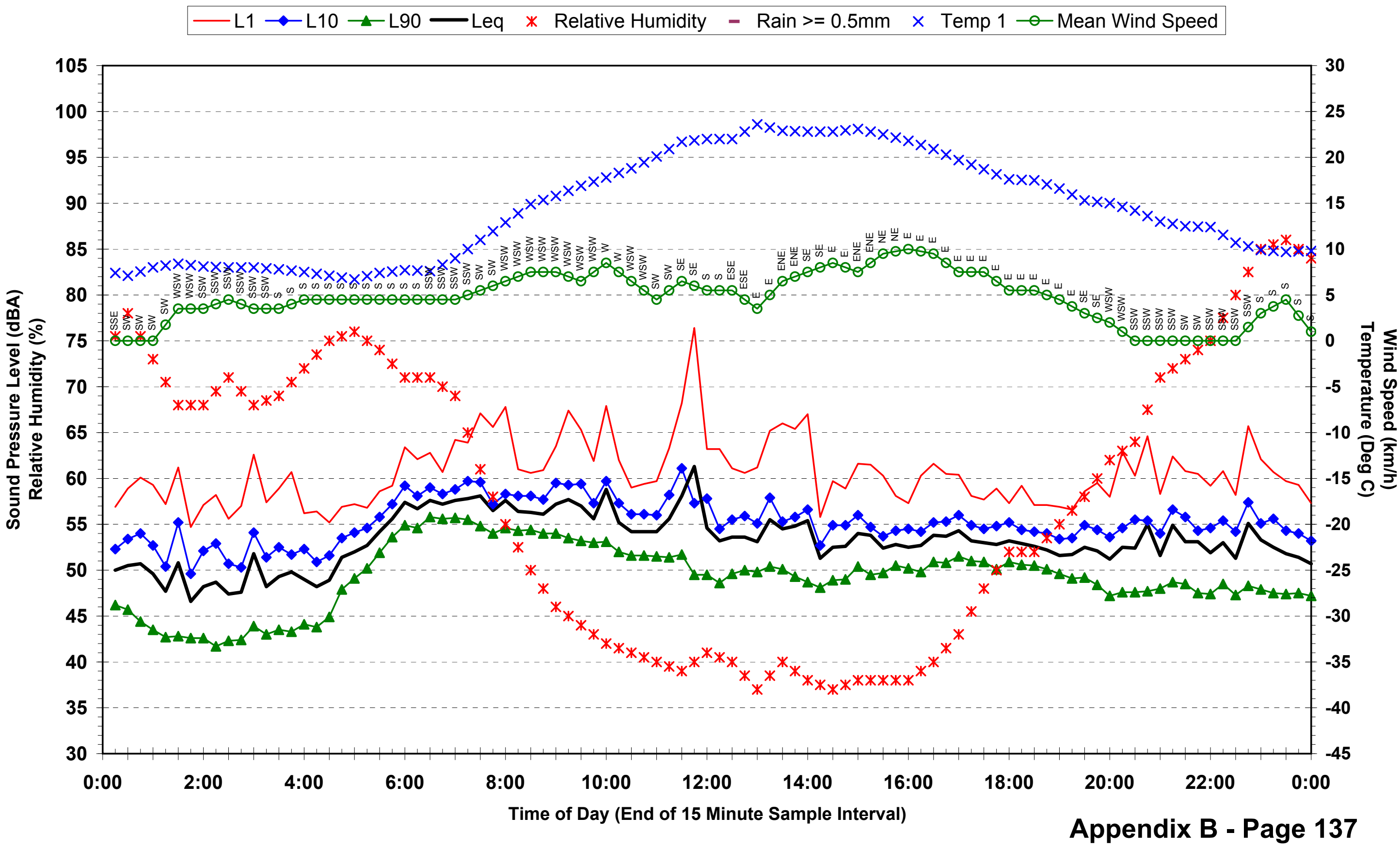
Statistical Ambient Noise Levels
Location 13 - 9 Horrocks Street, Toowong - Wednesday 7 May 2008



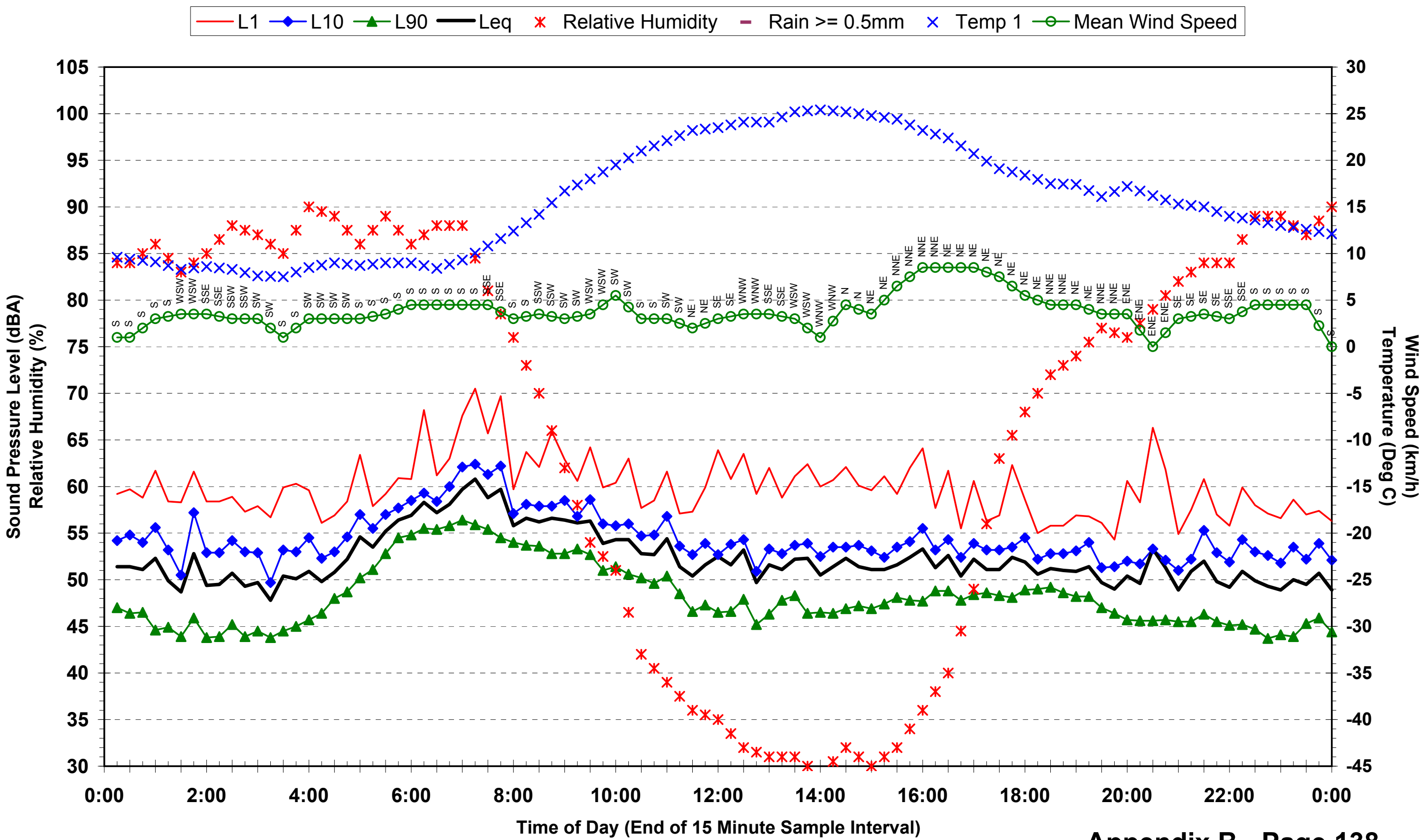
Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Tuesday 29 April 2008



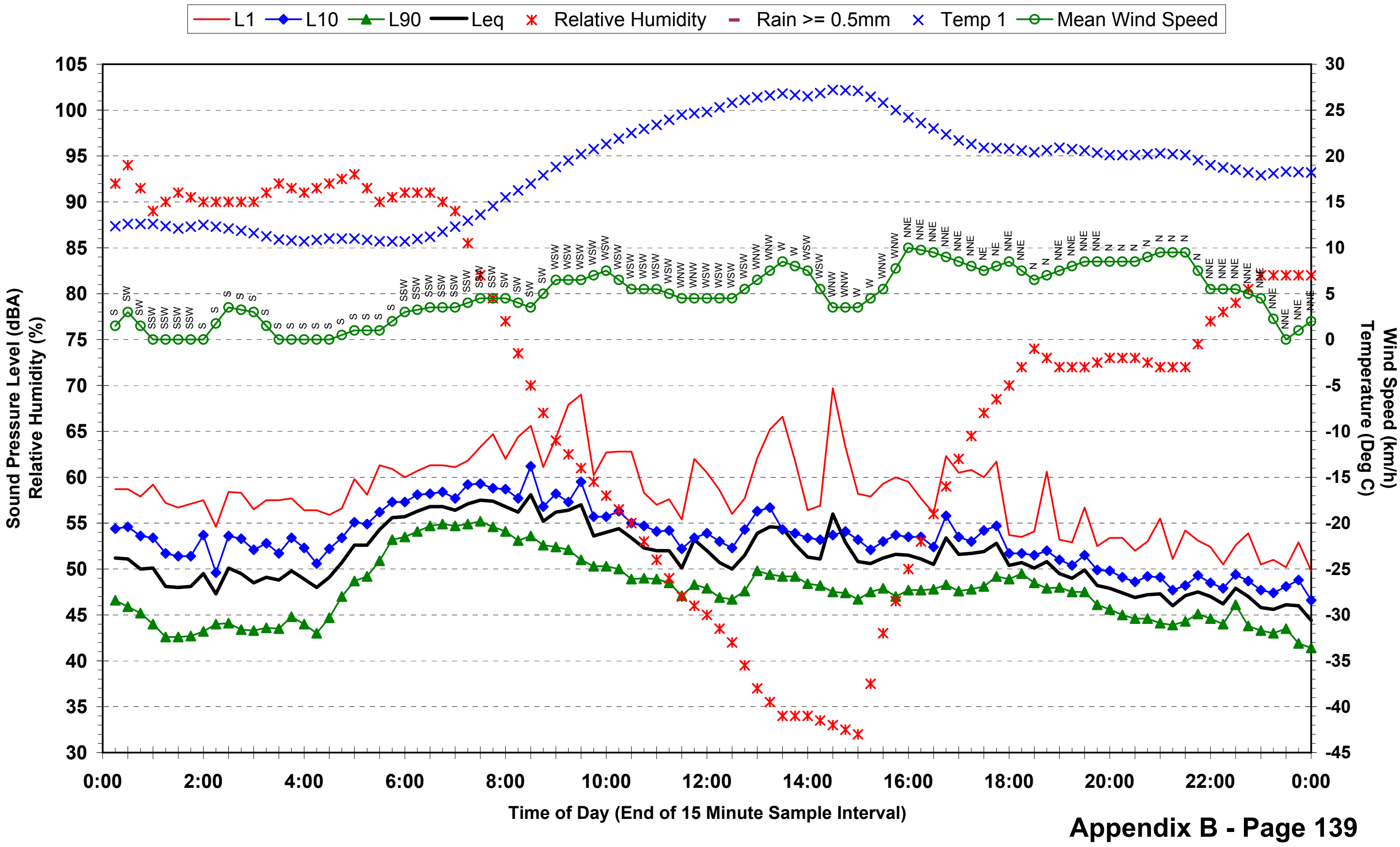
Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Wednesday 30 April 2008



Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Thursday 1 May 2008



Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Friday 2 May 2008

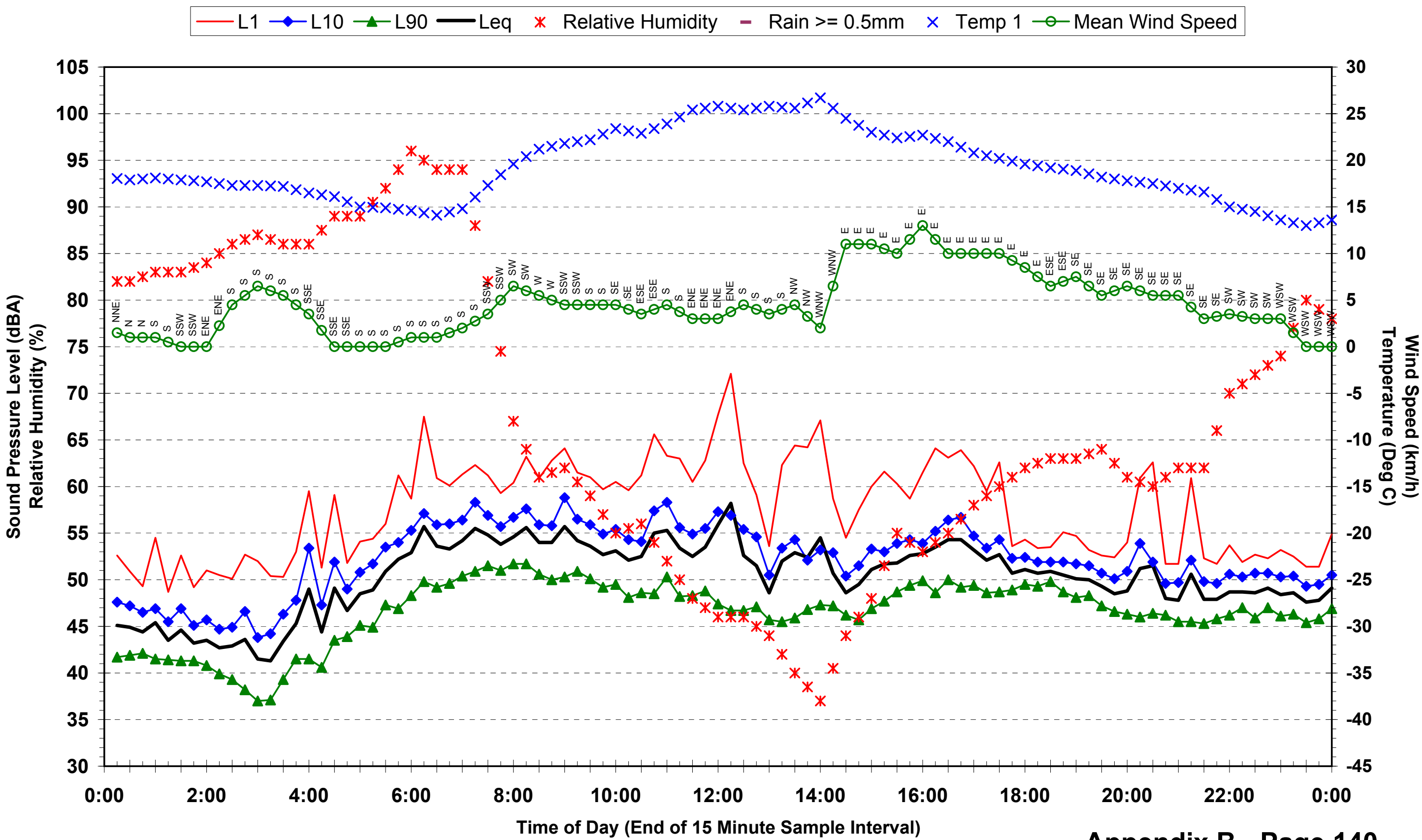


Appendix B - Page 139

Ambient Conditions

Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Saturday 3 May 2008

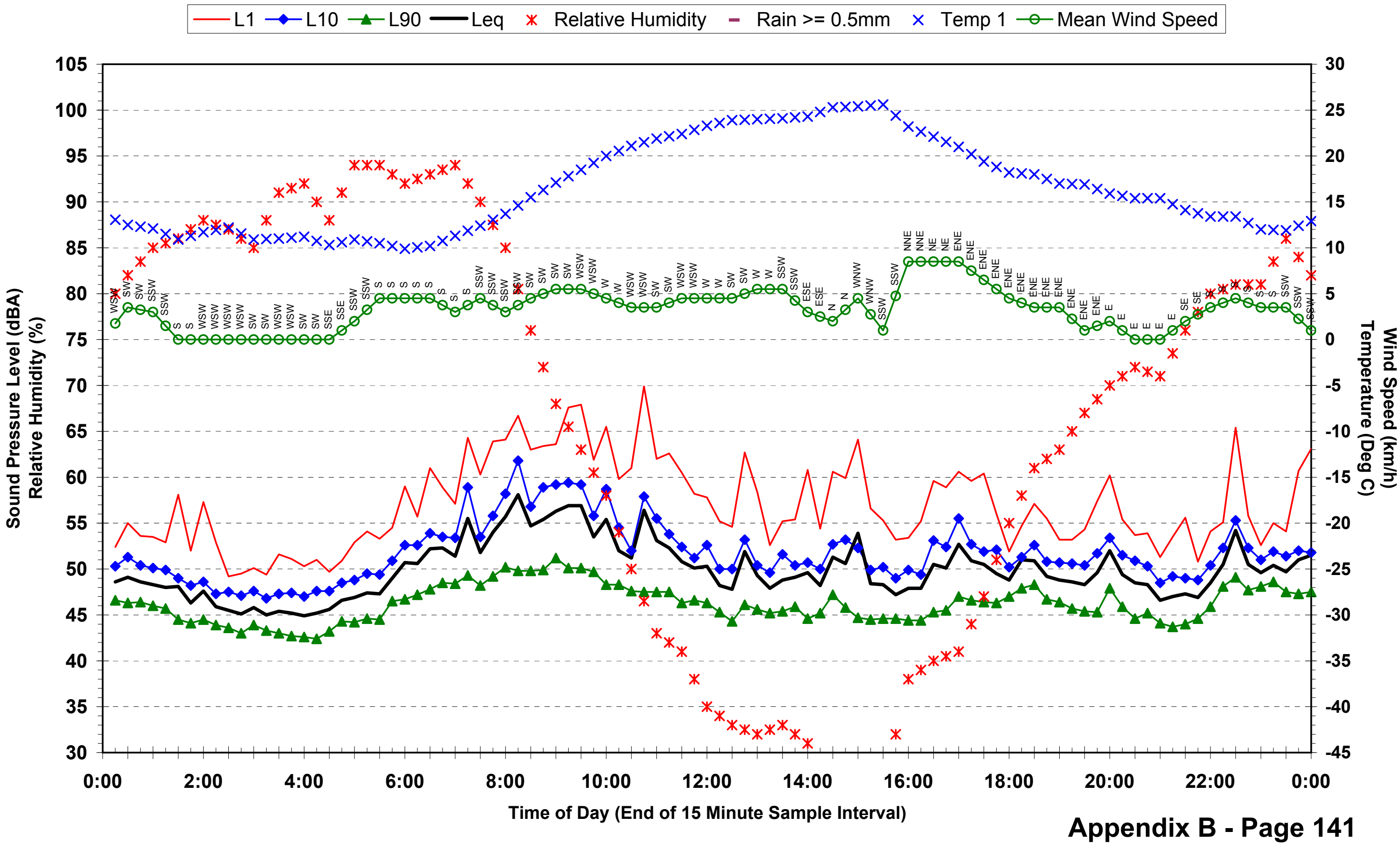


Appendix B - Page 140

Ambient Conditions

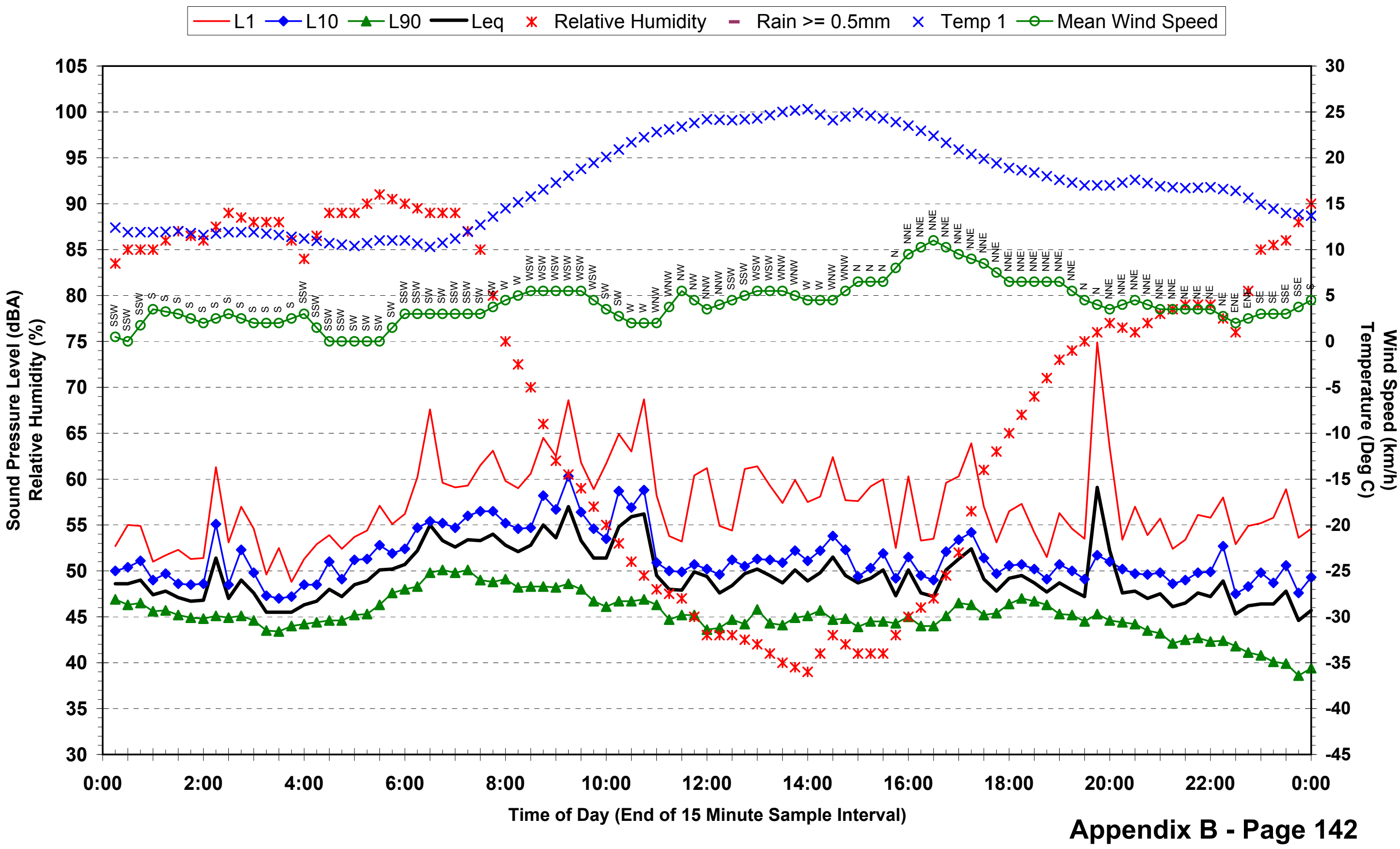
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Sunday 4 May 2008



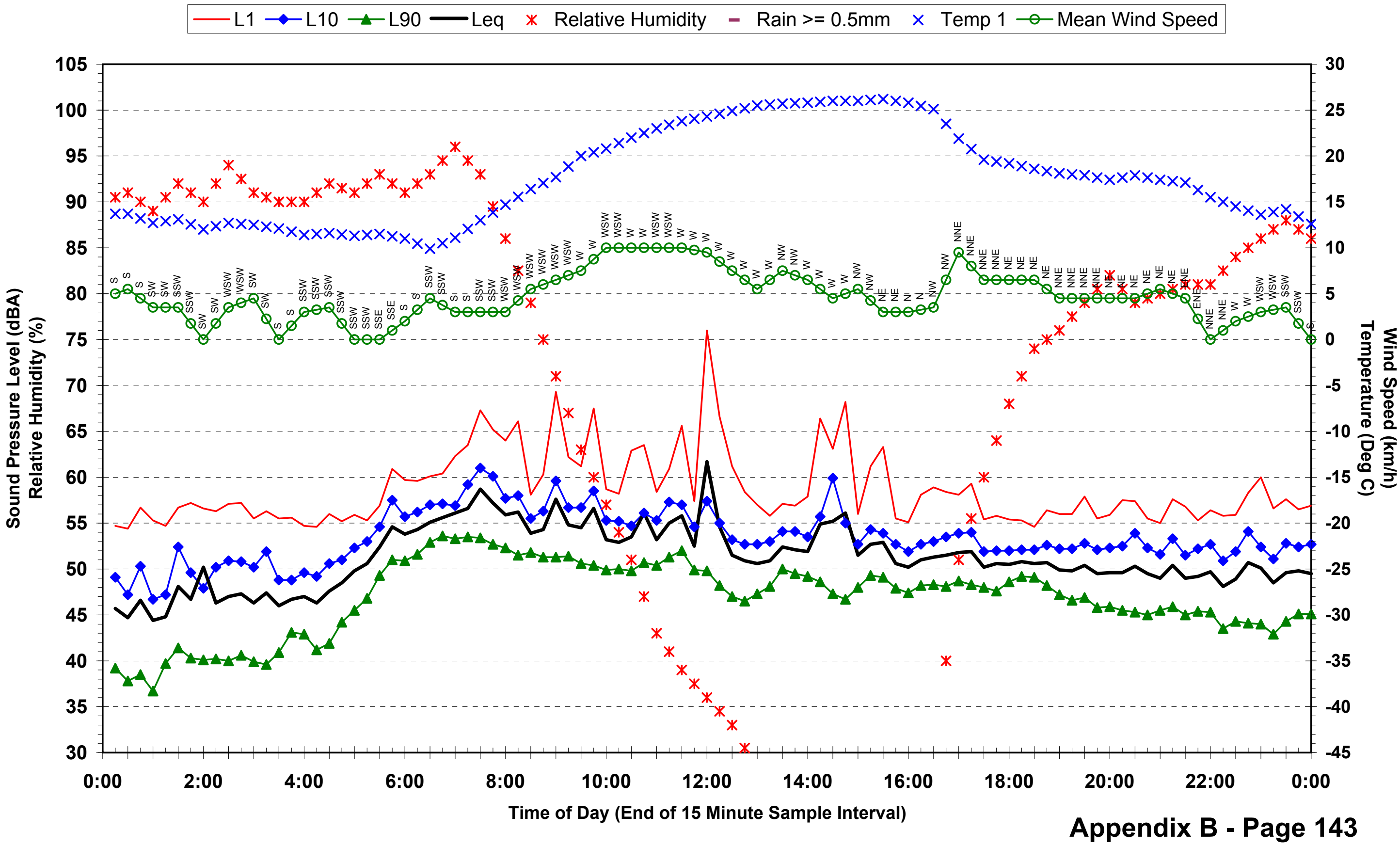
Appendix B - Page 141
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Monday 5 May 2008



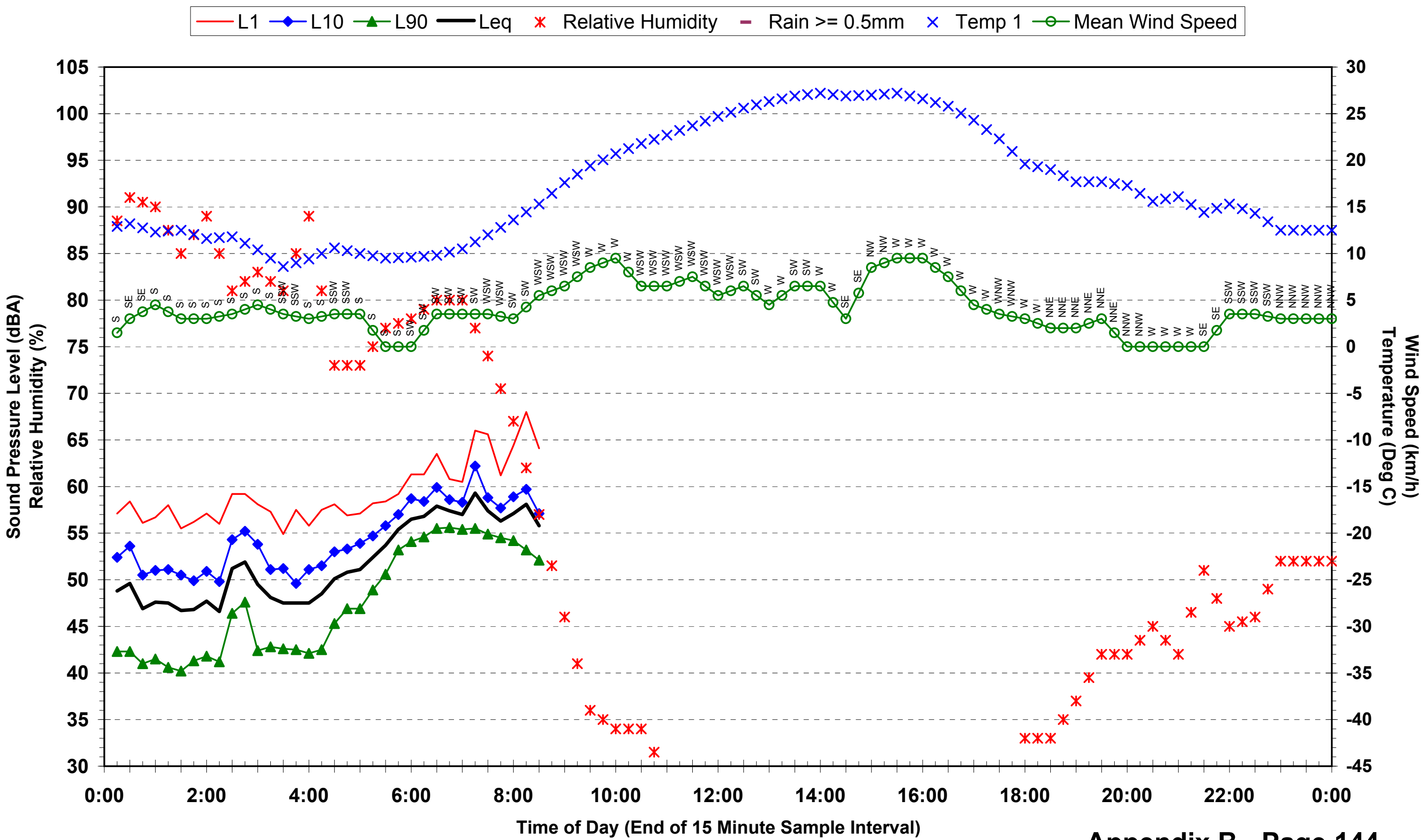
Appendix B - Page 142
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Tuesday 6 May 2008



Appendix B - Page 143
Ambient Conditions
Heggies Report 20-1854

Statistical Ambient Noise Levels
Location 14 - QUT Kelvin Grove Campus - Wednesday 7 May 2008



Appendix B - Page 144
Ambient Conditions
Heggies Report 20-1854