Sydney Opera House

Building Renewal

Noise Impact Assessment for DA3 - SSD 8663

R07

Issue (Rev A) | 15 May 2018

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Document Verification

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Job title		Building Renewal			**Job number**
Document title		Noise Impact Assessment for DA3 - SSD 8663			**File reference**
Document ref		R07			
Revision	**Date**	**Filename**	2017-07-27 Noise Impact Assessment (DA3).docx		
Draft 1	28 Jul 2017	**Description**	First draft		
			Prepared by	Checked by	Approved by
		Name	N Boulter	D Jimenez	N Boulter
		Signature			
Draft 2	23 Oct 2017	**Filename**	2017-10-23 Noise Impact Assessment (DA3).docx		
		Description	Updates with Client comments		
			Prepared by	Checked by	Approved by
		Name	N Boulter	D Jimenez	N Boulter
		Signature			
Draft 3	3 Nov 2017	**Filename**	2017-11-01 Noise Impact Assessment (DA3).docx		
		Description	General updates		
			Prepared by	Checked by	Approved by
		Name	N Boulter	D Jimenez	N Boulter
		Signature			
Issue	18 Nov 2017	**Filename**	2017-11-18 Noise Impact Assessment (DA3)_issue.docx		
		Description	Issue		
			Prepared by	Checked by	Approved by
		Name	N Boulter	D Jimenez	N Boulter
		Signature			
				Issue Document Verification with Document	✓

Document Verification

Job title		Building Renewal			**Job number** 245827
Document title		Noise Impact Assessment for DA3 - SSD 8663			**File reference**
Document ref		R07			
Revision	**Date**	**Filename**	2018-05-15 Noise Impact Assessment (DA3)_Issue (Rev		
Issue (Rev A)	15 May 2018	**Description**	Revision of modelling and Noise Impact Assessment to remove UTS from scope, as per Variation 2 registered 24/04/2018		
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		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
				Issue Document Verification with Document	✓

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1 Introduction

This report presents the results of an assessment of noise from some of the proposed works for the Sydney Opera House (SOH) Building Renewal project as covered by the DA3 submission.

A glossary of acoustic terminology has been included in Appendix B.

1.1 Scope of Assessment

This assessment reviews operation and construction noise issues for the following proposed components of the SOH Building Renewal Works Package 3 projects included as part of Development Application 3:

- Concert Hall (CH)
- Creative Learning Centre (CLC)

2 Summary

The assessment of noise levels has shown that operational noise as a result of the modifications is not likely to have any adverse impact on noise sensitive receivers around the site.

2.1 Construction Noise

Most of the construction works for the project are internal and will take place in spaces that are extremely well insulated against noise transfer. External work at night will be limited to *occasional* deliveries where these cannot be safely undertaken during normal working hours or because of large loads.

Calculations show that construction noise levels should not exceed the appropriate criteria at any time.

Notwithstanding the above, the Sydney Opera House (SOH) has recognised noise issues affecting nearby neighbours during external construction works in the past. Therefore the Sydney Opera House intends that contractors who are undertaking noisy external works identify mitigation measures for this work in their Construction Noise Management Plan (CNMP) which they will be required to prepare before work starts on site. This CNMP will be reviewed by the SOH and their noise consultants prior to approval and implementation on site.

The Contract with the Managing Contractor will include a clause allowing SOH to disallow any equipment that it considers to be excessively noisy. Similarly the Managing Contractor may include incentives, as it sees fit, for sub-contractors who can provide noise mitigation measures as part of their contract works.

The following noise limits will be applied:

Receiver	Time Period[1]	Warning level, $L_{Aeq(15min)}$	Maximum Level, $L_{Aeq(15min)}$
Bennelong Apartments	Day (standard hours)	65 dB	68 dB
	Day (outside hours)	60 dB	63 dB
	Evening	59 dB	62 dB
	Night	50 dB	53 dB
Kirribilli	Day (standard hours)	61 dB	64 dB
	Day (outside hours)	56 dB	59 dB
	Evening	54 dB	57 dB
	Night	48 dB	51 dB
Potts Point	Day (standard hours)	58 dB	61 dB
	Day (outside hours)	53 dB	56 dB
	Evening	53 dB	56 dB
	Night	47 dB	50 dB

Should complaints be received, attended acoustic monitoring will be undertaken to ascertain the 'noisier' work activities and address specific work practices and locations to better alleviate noise complaints from that particular activity.

Following identification that all noise levels have returned to being consistently below the above maximum levels the monitoring will revert to remote monitoring.

Nearby residents will be provided with a notice that informs them of the nature of the works, the duration and the extent of works being undertaken. 24hr contact details will be provided to allow complaints to be logged and addressed as soon as possible by the Opera House.

2.2 Operational Noise

The proposed upgrades are not expected to result in any increase in noise from normal operation, plant noise and events.

[1] *day* refers to 0700 to 1800h, *evening* refers to 1800 to 2200h and *night* refers to 2200h to 0700h. *Standard hours* refers to standard working periods (Monday to Friday 0700 to 1800h and Saturday 0800 to 1300h).

3 Proposed Works

3.1 Construction

The exact construction techniques and equipment will be finalised by the eventual contractor(s) for the project. Based on the best information available, the following are likely to be involved.

- External demolition (removal of façade and road pavement/curbing)
- Internal demolition
- Concreting
- External fitout works
- Internal fitout works
- Waste handling/removal
- Deliveries/removal

More detail is given in Section 7.1 of this report. Some works will need to be done outside of normal working hours because of the sensitivity of the internal spaces within the Opera House.

3.2 Proposed Uses

The following uses are anticipated by SOH for the different spaces.

Creative Learning Centre (CLC)

- New creative learning programs – the space is anticipated to primarily be used for creative play and teaching and learning activities with school children
- Use of the space may include amplified music, etc. but this is not expected to be a significant factor as no external/outdoor interface is proposed with the space (other than entry / exit)
- Patron arrival for program sessions with entrance by patrons from the Western Broadwalk and the Western Foyer as pedestrians only (no vehicles).

Proposed capacities of the CLC:

- Primary learning space: 147 people standing and 32-49 for creative play
- Secondary/Digital learning space: 46 people standing and 10-16 for creative play

It is intended that the CLC be used as a site office for most of the construction period.

Concert Hall

The usage of the Concert Hall will be unchanged as a result of the development. It will be used to host a wide variety of noise generating and acoustically sensitive events.

As part of the upgrades to the Concert Hall, some replacement Air Handling Units (AHUs) are to be installed and there will be some new Smoke Extract Fans (which will only run during emergencies). There is a new exhaust opening in Plantroom 16.

4 Existing Environment

The NSW Industrial Noise Policy (INP)[2] sets out a methodology to characterise the background noise environment at a proposed development and to derive appropriate criteria for noise from plant affecting the environment.

This is based on the levels of existing noise at sensitive receivers located around the site which in turn are derived from an extensive survey of existing ambient noise levels. Methods outlined within the NSW INP were used to measure and derive the Rating Background Level (RBL). Subsequent noise criteria for different applications were then derived based on the RBL data as presented in Section 5.

Further details of the noise surveys carried out are provided in Appendix A.

4.1 Description of Site

The site is located on the Bennelong Point peninsula in Sydney Harbour and is near to a major passenger ferry terminal. The area around the Opera House is effectively pedestrianised although there are some occasional deliveries and drop-offs that visit the southern end of the site. Most of the traffic visiting the site accesses the adjacent car parking via an underground route.

The site is characterised by general pedestrian activity and noise from the harbour activity, with occasional aircraft movements. The background noise environment also contains traffic noise from the Cahill Expressway (located to the south and west on the Harbour Bridge) and rail noise from the Harbour Bridge (located to the west).

[2] NSW Industrial Noise Policy. Environment Protection Authority. January 2000

4.2 Noise Sensitive Receivers

The nearest residential noise sensitive receivers with potential to be affected are located as shown in Figure 1.

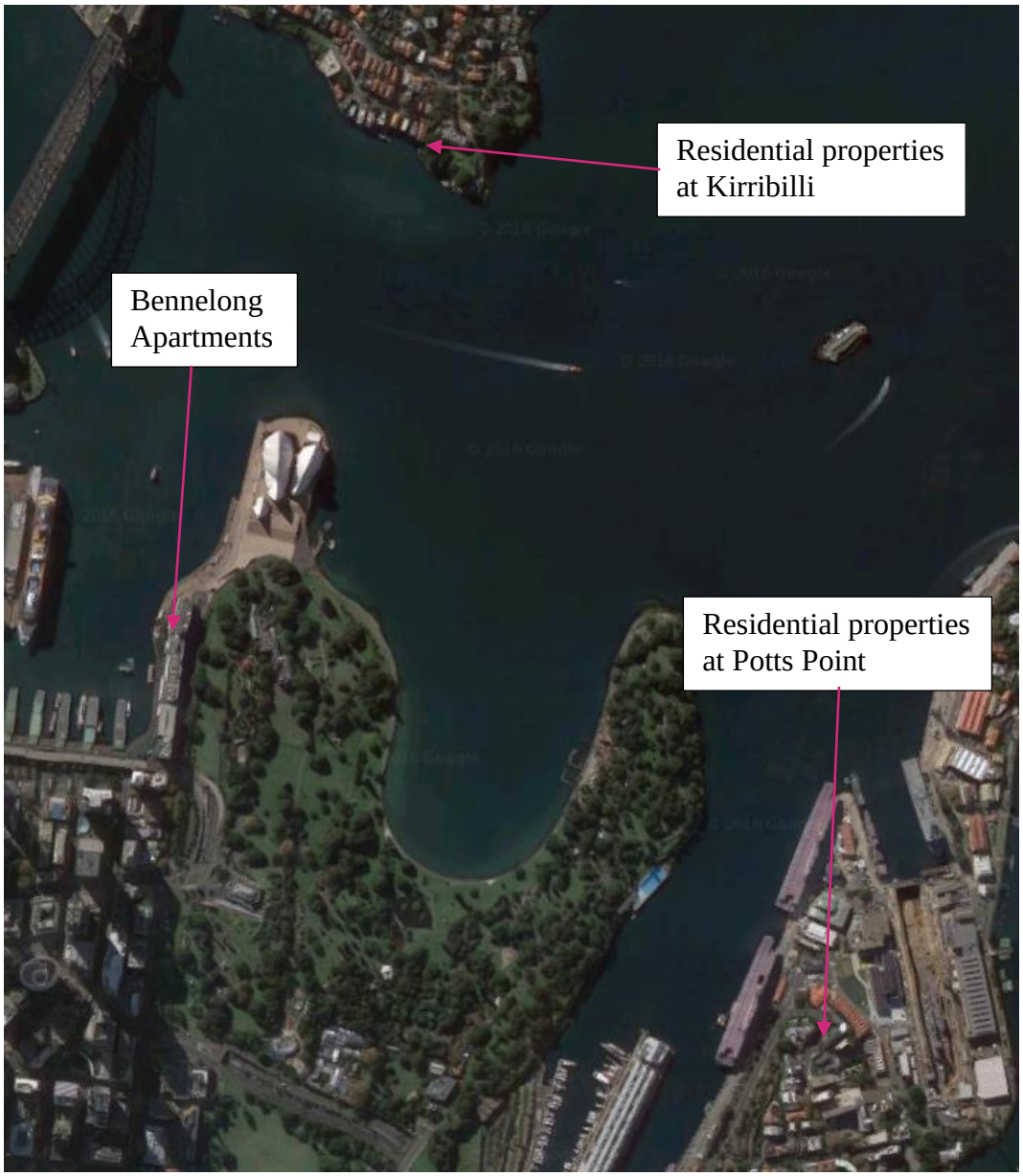


Figure 1: Noise sensitive receivers (image courtesy of Google Maps)

4.3 Measurement of existing noise levels

Surveys of the existing noise levels at the nearest noise sensitive receivers have been conducted.

Measurements at Kirribilli Point (near harbour in front of the southern façade of 29 Waruda Street, adjacent to Beulah Street Wharf) were undertaken by Arup

using unattended noise logging over the course of one week, supplemented with attended measurements.

Unattended noise logging measurements by Auditoria were undertaken to determine the noise levels at the Bennelong Apartments, East Circular Quay on Levels 4 and 9.

For potential receivers at Potts Point, the significant source-receiver distance (>1 km) means that significant impacts are unlikely and hence background noise measurements were not taken for these receivers. Indicative background noise levels from a previous project in Woolloomooloo have been used to represent the likely existing noise environment at Potts Point. The measurements in Woolloomooloo were previously undertaken by Arup at 31 Nicholson Street using unattended noise logging over the course of one week, along with attended measurements.

Further details of the noise surveys carried out are provided in Appendix A.

5 Noise Criteria

5.1 Background Noise Levels

Single-number background noise measurements ($L_{A90,15min}$ determined using the "tenth percentile" method and time periods as per the NSW Industrial Noise Policy) are summarised in Table 1. Refer to Appendix A for further details.

A customised Rating Background Level (RBL) has also been derived using only 10pm – 12am measurement data at the Kirribilli and Bennelong Apartments receivers to represent a 'worst case' (i.e. lowest background noise) condition that may occur during the typical operating time limits assumed for activities in the Concert Hall or within the Creative Learning Centre.

Table 1: Background noise levels at noise sensitive receivers, dB re 20µPa

Receiver	Time Period	Rating Background Level ($dBL_{A90,15min}$)
Bennelong Apartments	Day	58
	Evening	57
	Night	48
	10pm – Midnight	56
Kirribilli	Day	54
	Evening	52
	Night	46
	10pm - Midnight	51
Potts Point	Day	51
	Evening	51
	Night	45

5.2 Operational Plant Noise Criteria

The only changes affecting plant noise is the provision of a new intake for Plant Room 16 on the Western Façade, the replacement of the AHUs and the installation of new Smoke Extract Fans.

The criteria for plant noise are derived from the NSW Industrial Noise Policy (INP). In addition, plant noise will also be controlled local to the Opera House in order that the external walkways around the Opera House are not disturbed.

5.3 Operational Event Noise Criteria

There are successful existing precedents regarding noise limits from the SOH Northern Broadwalk as defined in the approved Conditions of Consent from a

previous Development Application[3] (DA). The DA sets out various noise criteria which are shown below. These limits are used as a reference for assessment against within this report.

The DA defines two types of external events, these being:

- low impact events (with up to 250 people)
- medium impact events (with up to 1000 people)

Low impact events are allowed for up to 12 days per month and medium impact events for up to 40 times per year. Events have to finish by 2400h.

Noise levels are limited to the following which apply between the hours of 10am to 11pm on Sunday to Thursday and between the hours of 10am to 12 midnight on Friday, Saturday and the eve of a public holiday (refer to Condition of Consent 38).

- 55 dBL_{Amax} and 70 dBL_{Cmax}; or
- dBL_{Amax} not to exceed the background noise level (dBL_{A90}) by more than 5dB(A) and the L_{Cmax} must not exceed the L_{Amax} by more than 15dB

Note: The ambient noise measurements taken as part of this study (refer to Table 1 *and Appendix A) show that before midnight the existing background noise level is above 50 dBL_{A90} so the above criteria a) of 55 dBL_{Amax} and 70 dBL_{Cmax} would apply as the limiting criteria.*

The limits apply at noise sensitive receivers (e.g. residences) and the main locations are identified in the DA conditions as Beulah Street Wharf (off Waruda Street) in Kirribilli and at a point within one metre of the residential boundary nearest to SOH at Bennelong Apartments, East Circular Quay.

5.4 Construction Noise Criteria

This report only considers impacts on receivers external to the Sydney Opera House from construction works at the SOH. Impacts to internal sensitive spaces within the Sydney Opera House will be managed via administrative controls by scheduling of noise-generating activities outside of the operational hours of the SOH venues.

For external receivers, the NSW *Interim Construction Noise Guideline* (ICNG) provides recommended noise levels for airborne construction noise at sensitive land uses for State-controlled projects in NSW. The guideline provides construction management noise levels above which all feasible and reasonable work practices should be applied to minimise the construction noise impact. The ICNG works on the principle of a "screening" criterion – if predicted or measured construction noise exceeds the ICNG levels then the construction activity must implement all "feasible and reasonable" work practices to reduce noise levels. As

[3] DA 444-10-2003 from June 2004 for use of the Northern Broadwalk for temporary functions. Department of Infrastructure Planning and Natural Resources.

such, the noise targets set by the ICNG are "management levels" for noise rather than strict "noise limits".

The ICNG sets out management levels for noise at noise sensitive receivers, and how they are to be applied. These management noise levels for residential receivers are reproduced below, in Table 2. Noise levels apply at the worst affected property boundary of the residence, at a height of 1.5 m above ground level. If the property boundary is more than 30 m from the residences, the noise levels apply at the most noise-affected point within 30 m of the residence.

Table 2: ICNG management levels for airborne construction noise at residences

Time of day	**Management Level, $L_{Aeq(15min)}$**	**How to apply**
Recommended standard hours: Monday to Friday 7 am to 6 pm Saturday 8 am to 1 pm No work on Sundays or Public Holidays	Noise affected RBL + 10 dB	The noise affected level represents the point above which there may be some community reaction to noise. Where the predicted or measured $L_{Aeq\ (15\ min)}$ is greater than the noise affected level, the proponent should apply all feasible and reasonable work practices to meet the noise affected level. The proponent should also inform all potentially impacted residents of the nature of works to be carried out, the expected noise levels and duration, as well as contact details.
	Highly noise affected 75 dB(A)	The highly noise affected level represents the point above which there may be strong community reaction to noise. Where noise is above this level, the relevant authority (consent, determining or regulatory) may require respite periods by restricting the hours that the very noisy activities can occur, taking into account: • Times identified by the community when they are less sensitive to noise (such as before and after school for works near schools, or mid-morning or mid-afternoon for works near residences). • If the community is prepared to accept a longer period of construction in exchange for restrictions on construction times.
Outside recommended standard hours	Noise affected RBL + 5 dB	A strong justification would typically be required for works outside the recommended standard hours. The proponent should apply all feasible and reasonable work practices to meet the noise affected level. Where all feasible and reasonable practices have been applied and noise is more than 5 dB(A) above the noise affected level, the proponent should negotiate with the community.

For work within standard construction hours, if after implementing all "feasible and reasonable" noise levels the site still exceeds the Noise Affected Level, the

ICNG does not require any further action – since there is no further engineering scope for noise mitigation.

For out-of-hours work, the ICNG uses a level 5 dB above the noise-affected level as a threshold where the proponent should negotiate with the community.

Although the ICNG does not use this terminology, in this report, the term "Highly-Noise Affected Level" has been used to refer to this level (i.e. 5 dB(A) above the Noise Affected Level for out-of-hours work) for reasons of brevity.

Table 3: ICNG screening criteria for SOH Construction Works, dB re 20µPa

Receiver	Time Period	Noise Affected Level, $L_{Aeq(15min)}$	Highly Noise Affected Level, $L_{Aeq(15min)}$
Bennelong Apartments	Day (standard hours)	68 dB	75 dB
	Day (outside hours)	63 dB	68 dB
	Evening	62 dB	67 dB
	Night	53 dB	58 dB
Kirribilli	Day (standard hours)	64 dB	75 dB
	Day (outside hours)	59 dB	64 dB
	Evening	57 dB	62 dB
	Night	51 dB	56 dB
Potts Point	Day (standard hours)	61 dB	75 dB
	Day (outside hours)	56 dB	61 dB
	Evening	56 dB	61 dB
	Night	50 dB	55 dB

5.4.1 Sleep disturbance

Noise emanating from project has been assessed for its potential to disturb sleep. The NSW EPA has made the following policy statement with respect to sleep disturbance:

> *Peak noise level events, such as reversing beepers, noise from heavy items being dropped or other high noise level events, have the potential to cause sleep disturbance. The potential for high noise level events at night and effects on sleep should be addressed in noise assessments for both the construction and operational phases of a development. The INP does not specifically address sleep disturbance from high noise level events.*

Research on sleep disturbance is reviewed in the NSW Road Noise Policy. *This review concluded that the range of results is sufficiently diverse that it was not reasonable to issue new noise criteria for sleep disturbance.*

From the research, the EPA recognised that the current sleep disturbance criterion of an $L_{A1,\ (1\ minute)}$ *not exceeding the* $L_{A90,\ (15\ minute)}$ *by more than 15 dB(A) is not ideal. Nevertheless, as there is insufficient evidence to determine what should replace it, the EPA will continue to use it as a guide to identify the likelihood of sleep disturbance. This means that where the criterion is met, sleep disturbance is not likely, but where it is not met, a more detailed analysis is required.*

The detailed analysis should cover the maximum noise level or $L_{A1,\ (1\ minute)}$*, that is, the extent to which the maximum noise level exceeds the background level and the number of times this happens during the night-time period. Some guidance on possible impact is contained in the review of research results in the* NSW Road Noise Policy. *Other factors that may be important in assessing the extent of impacts on sleep include:*

- *how often high noise events will occur*
- *time of day (normally between 10pm and 7am)*
- *whether there are times of day when there is a clear change in the noise environment (such as during early morning shoulder periods).*

The $L_{A1,\ (1\ minute)}$ *descriptor is meant to represent a maximum noise level measured under 'fast' time response. The EPA will accept analysis based on either* $L_{A1,\ (1\ minute)}$ *or* $L_{A,\ (Max)}$*.*
Source: http://www.epa.nsw.gov.au/your-environment/noise/industrial-noise/nsw-industrial-noise-policy/applying-industrial-noise-policy

In summary, the sleep disturbance criteria of $L_{A1(1min)} \leq L_{A90(15min)} + 15dB(A)$ is to be used for initial assessment. The L_{Amax} may be used as an alternative to the $L_{A1(1min)}$. It is noted that the background $L_{A90(15minute)}$ noise level used for establishing the sleep disturbance criteria includes all background noise including noise from the project.

The sleep disturbance criteria for the project are presented in

Table 4.

Table 4: Sleep disturbance criteria

Receiver	**Sleep disturbance criteria, 10pm - 7am, , $L_{A1,1min}$, dB(A)**
	$L_{A90(15min)}$ + 15
Bennelong Apartments	63 dB
Kirribilli	61 dB
Potts Point	60 dB

6 Operational Noise

6.1 Creative Learning Centre

All activity in these space is expected to take place internally and not expected to generate high levels of noise. The Creative Learning Centre (CLC) is a fully enclosed space with full air conditioning and it is not envisaged that there be any loud activities that would take place with doors open. The space is anticipated to primarily be used for creative play and for teaching and learning activities with school children.

It is worth noting that the Primary Learning Space within the CLC is buffered from the western façade by other spaces – a smaller Secondary/Digital Learning Space and a toilet block.

Prediction calculations have been done to check on potential noise breakout through the area of the northern glazed façade that faces Kirribilli. A 'loud' internal music noise level has been assumed as shown in Table 5 as representative of a worst case usage scenario.

Table 5: Assumed L_{10} sound pressure level incident directly on façade within the CLC

Event Type	Sound Pressure Level, L_{10} (dB re 20 µPa)									
	Single Figure		Octave Band Centre Frequency (Hz)							
	dB(A)	dB(C)	63	125	250	500	1k	2k	4k	8k
Loud Music (amplified)	90	97	93	92	88	88	84	83	77	70

Using *measured* data for the in-situ sound insulation of the existing façade type including doors (D_w 25, C_{tr} -2) and taking pessimistic assumptions about propagation losses using CONCAWE[5] Category 6 conditions (i.e. downwind), the noise level at Kirribilli and Bennelong apartments is calculated as less than 24 dBL_{A10}.

Predictions to each receiver location which allow for open doors are less than 41 dBL_{A10}, which is still more than 10 dB below the 'worst case' custom night time L_{A90} background noise levels at each location during assumed typical operating time limits (refer to the RBLs taken between 10pm – Midnight in Table 1).

No significant impact on the surroundings is therefore expected from the proposed activities in the CLC.

[5] The propagation of noise from petroleum and petrochemical complexes to neighbouring communities. CONCAWE report no 4/81.

6.2 Concert Hall

6.2.1 Building Envelope

The concert hall will be undergoing a significant internal refurbishment as part of the project. Whilst there will be internal changes to improve the acoustic and operational conditions, no major changes are planned to the structural envelope of the venue. There will remain a continuous double skin to the Concert Hall which will serve to reduce noise intrusion into this extremely noise sensitive space. These constructions will be sufficient to control noise breakout to avoid any issues with noise affecting any residential receivers.

6.2.2 AHU Plant

Some of the plant will be replaced, particularly three large AHUs. The plant is being carefully selected to minimise noise levels to protect both the internal listening environment and to reduce noise transfer to atmosphere.

Calculations show that noise from this plant would be less than 50 dB(A) at the publically accessibly walkways around the Opera House (in order to protect the amenity of these areas).

Noise from the AHU plant at the residential receivers will be less than 30 dB(A). On that basis, no additional acoustic treatment is required for the AHU plant. Sound Power Levels for the proposed plant are shown below.

Table 6: Sound Power Data for Proposed New AHU Plant

Item Reference	**Sound Power Level (dB re 10^{-12}W) to Atmosphere Octave Band Centre Frequency (Hz)**							
	63	125	250	500	1k	2k	4k	8k
17-AHU-1	83	92	93	95	92	90	79	79
21-AHU-1A	73	83	80	80	89	82	77	73
21-AHU-1B	73	83	80	80	89	82	77	73

6.2.3 Smoke Extract Plant

The project will include the installation of new smoke extract fans (two run and two standby). These will only be operated in an emergency and for occasional testing. They will **not** be used for the clearance of theatrical haze or any non-emergency uses.

As with the AHUs, low noise plant has been selected. Calculations using data from the proposed supplier show that noise from the smoke extract fans would be less than 30 dB(A) at the nearest noise sensitive receivers.

The sound power data is shown below.

Table 7: Sound Power Data for Proposed New Smoke Extract Plant

Item Reference	Sound Power Level (dB re 10^{-12}W) to Atmosphere Octave Band Centre Frequency (Hz)							
	63	125	250	500	1k	2k	4k	8k
21-SPF-1	98	90	88	90	87	84	82	78
21-SPF-2	98	90	88	90	87	84	82	78
21-SPF-3	98	90	88	90	87	84	82	78
21-SPF-4	98	90	88	90	87	84	82	78

6.2.4 Ancillary Plant

A small kitchen exhaust fan and return air fan will also be incorporated. The sound power data is as follows:

Table 8: Sound Power Data for Ancillary Plant

Item Reference	Sound Power Level (dB re 10^{-12}W) to Atmosphere Octave Band Centre Frequency (Hz)							
	63	125	250	500	1k	2k	4k	8k
Kitchen Exhaust	78	73	67	64	59	55	52	48
Return Air Fan RAF- 17-1	92	86	94	91	90	88	84	79

6.2.5 Noise Transfer via Ventilation Openings

The AHUs and smoke extract fans have roomside attenuation provided to control plant noise and also to limit external noise intrusion in the Concert Hall. These attenuators, and the acoustically treated ductwork, will ensure that noise breakout from events via the plant connections to the envelope will not be significant.

7 Construction Noise

7.1 Assumptions

Indicative construction activity noise source levels have been assumed for the construction works, based on previous construction noise assessments for building projects conducted by Arup and detailed discussions with construction specialists on the likely construction methodology for the project.

A majority of the construction work will take place within the Opera House. As the Opera House will still be in use during the works, much of the noisier construction work will have to happen outside normal construction working hours and at night.

The following major construction activities have been modelled:

- External works – this will involve the removal of glazed façade panels to provide access. A temporary opening will be created in the glazed part of the west facing façade to allow access to the Concert Hall for deliveries of large items. This opening will be provided with temporary doors until the glazing is re-installed. Note: there will be no external demolition.
- Internal demolition – work will be done with electrically powered tools and when all façade openings are closed (including temporary openings). Bobcat with nibbler used to remove stage
- Concreting – concrete delivered by trucks to semi-enclosed concrete pump at the central passage. Vibrators used internally.
- External fitout works – creation of one opening for new extract fan
- Internal fitout works – erection of new partitions, finishes etc and installation of new plant and equipment.
- Waste Handling/ removal – mostly undertaken using conveyors or chutes to move materials to bins in the existing underground loading bay.
- Deliveries/removal – mostly via existing underground routes although some of the larger items will need to be delivered through the southern foyer and under the steps.
- Temporary mobile cranes will be used and manual handling minimised.

For each activity, typical construction equipment used for that activity has been combined into an overall source sound power level for the activity, accounting for the likely usage patterns of items of equipment over a typical 15-minute period (which is the assessment time frame for construction noise levels under the ICNG).

It is worth noting that many of the deliveries/removals are expected to make use of the underground route and so will not disturb the nearest residential receivers from the noise of loading and unloading activities. Concrete trucks will deliver material at night for the concreting but only small volumes of concrete are required. A maximum of two trucks per night is expected. Trucks will not queue externally.

The site facilities will mostly be located under the steps and in the Creative Learning Centre (see Figure 3) with some internal spaces being also used. The facilities are thus screened from the nearest residential locations.

7.2 Working Hours

The proposed working hours are defined in the Draft Construction Management Plan[6]. This proposes that work at night would only take place internally and would be restricted to operations which would otherwise be disruptive to Opera House operations *"but not audible outside the building"*. As noted above, the exception to this night-time ban on work would be the delivery of small loads of concrete and the delivery of large items that cannot be safely delivered during the day.

There will be no work on Sundays.

The Figure below shows the proposed shift patterns.

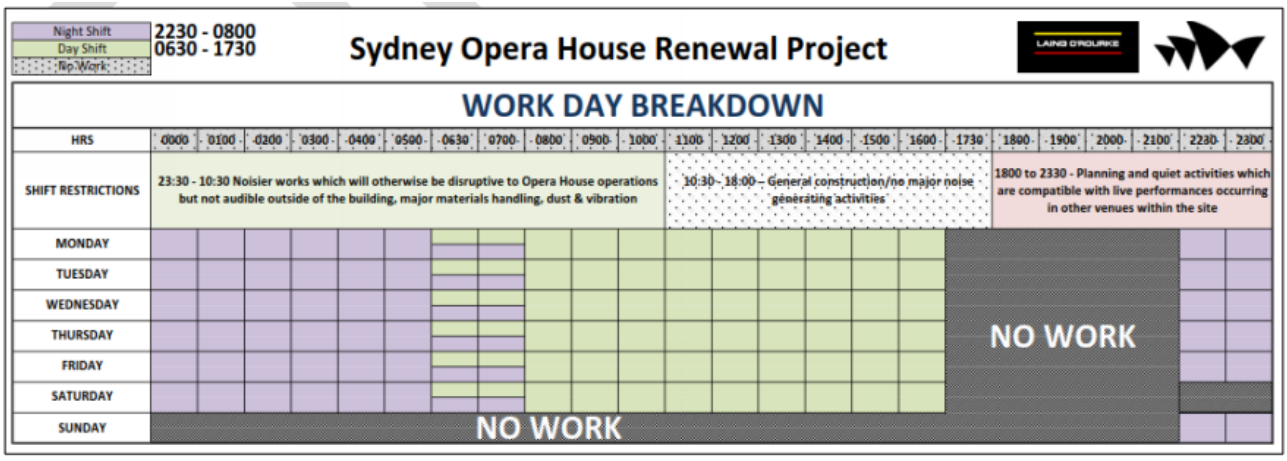


Figure 2: Work Day Breakdown (Provided by LORAC)

7.3 Source Noise Levels

Sound levels for items of construction plant have been obtained from the databases in BS5228.1[7] and AS2436[8].

Items of plant that have particularly-annoying characteristics (e.g. impulsive or tonal noise characteristics, such as cutting or drilling equipment) has had a +5 dB adjustment penalty applied to account for these characteristics, as required by the ICNG.

[6] Renewal DA3 Draft Construction Management Plan. Version 1

[7] British Standard BS5228-1: 2009 + A1 :2014 *Code of practice for noise and vibration control on construction and open sites – Part 1: Noise*

[8] Australian Standard AS2436 (2010) *Guide to noise and vibration control on construction, demolition and maintenance sites*

For on-site deliveries, equivalent line-source sound power levels have been calculated based on the published maximum pass-by levels for haul trucks from BS 5228.1.

For internal demolition works, minimal allowance has been made for the sound insulation of the building envelope (-15 dB for the fully internal works and -10 dB for the works near the facade). This is considered a pessimistic assumption.

Table 9 summarises the construction source levels and the major items of construction equipment modelled for each major construction activity:

Table 9 Construction Activities, SOH Building Renewal Works - DA3 Package

Activity	**Construction Equipment**	**Activity Sound Power Level, dB re 1pW**
External works	Mostly hand tools to remove façade elements and occasional mobile crane and forklifts / bobcats	$L_{eq,adj,15min}$ 99 dB(A)
Internal demolition	Demolition saw Core drill Concrete breakers (handheld) Small excavators/bobcats/forklifts (electric). Bobcat with nibbler to remove staging Work platforms	$L_{eq,adj,15min}$ 100 dB(A) (with allowance for façade losses)
Concreting	Concrete trucks (external) Concrete pumps (semi-internal) Vibrators (internal)	$L_{eq,adj,15min}$ 108 dB(A) (with allowance for façade losses)
External fitout works	Core drill Mobile cranes Small excavators/bobcats/forklifts	$L_{eq,adj,15min}$ 102 dB(A)
Internal fitout works	Hand tools Small excavators/bobcats Work platforms	$L_{eq,adj,15min}$ 89 dB(A) (with allowance for façade losses)
Waste handling/ removal	Conveyors and chutes	$L_{eq,adj,15min}$ 71 dB(A) (with allowance for façade losses)
Deliveries/removal	Haul truck/trailer	$L'_{eq,adj,15min}$ 71 dB(A)/m[9]

7.4 Predicted Noise Levels

Construction noise levels have been predicted for the sources given in Table 9 using a spreadsheet based noise model developed for the SOH Building Renewal Works Package 2 projects. The predictions generally implemented the CONCAWE environmental noise model, which allows prediction under adverse

9 Note this is a sound power per metre for a line source of noise corresponding to the haulage routes on site.

meteorological conditions to be made, with the exception of the ground effect component. CONCAWE was developed for propagation over sound-absorbing terrain (acoustically-"soft" ground) whereas the propagation geometry for the most-affected receivers from the SOH is mainly over acoustically-reflective ("hard") ground – i.e. pavement or water. To account for this, the ground effect component from the ISO 9613.2 noise model has been used.

Noise levels have been predicted under neutral ("still") meteorological conditions to show the average expected noise levels and to allow ready comparison of the relative impacts between individual activities; as well as under adverse ("downwind") conditions to indicate the potential increase in noise level under adverse conditions.

Indicative noise source locations were assumed as follows:

- Northern sources — At the northern façade intermediate between the JST and Concert Hall (Concert Hall and Creative Learning Centre works)

Due to the actual distance between the SOH construction works and noise sensitive receivers being of the order of >250 m, the actual source location chosen has minimal influence on the results, and hence activities in similar areas can be modelled as a single source location with minimal error. Allowance for acoustic screening by the Opera House itself has been made where appropriate (i.e. the Bennelong apartments would be screened by the Opera House from activities at the northern end)

For truck deliveries, line sources of noise have been used to model truck movements along the western boardwalk for occasional truck movements where it is not practicable to access the site via the underground VAPS route (e.g. delivery of large components or concrete). A maximum of one truck movement over a 15-minute assessment period has been assumed. Nighttime deliveries will be limited to Oversize or Overmass items in accordance with RMS requirements and for safety reasons.

A site plan showing the indicative construction source locations is presented in Figure 3.

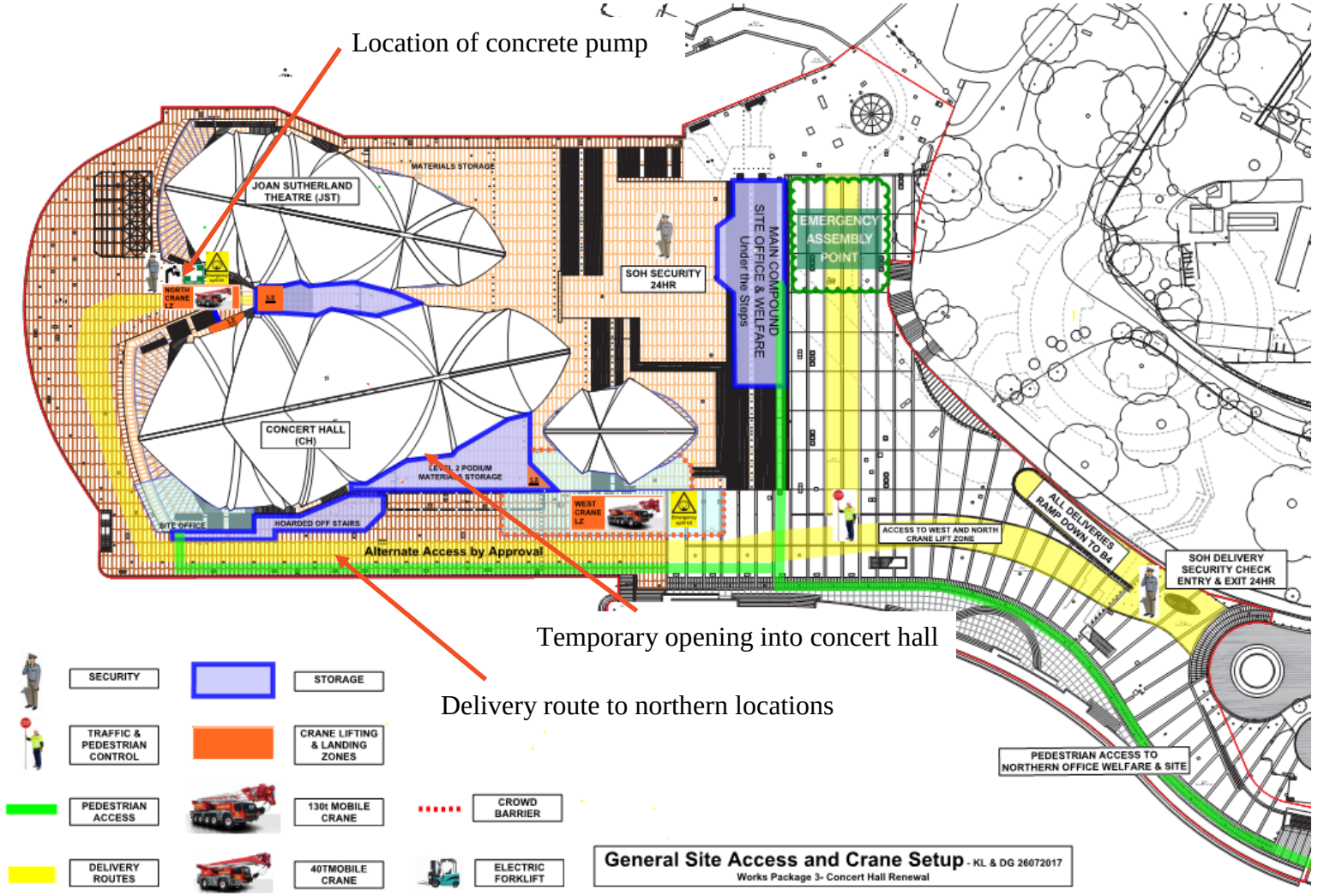


Figure 3: Indicative construction source locations, - DA3 Package works

For each of these source locations, the following tables (Table 10, and Table 11) present a summary showing the highest predicted noise level at each noise-sensitive receiver catchment (Bennelong Apartments, Kirribilli and Potts Point), and presents the ICNG construction screening criteria for comparison.

Table 10: Construction Noise Screening Calculations, Sydney Opera House, Northern Sources (Creative Learning Centre, Concert Hall), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level, dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Creative Learning Centre, Concert Hall	Internal Demolition	Bennelong	31 - 42	68	62	53
		Kirribilli	17 - 31	64	57	51
		Potts Point	< 20	61	56	50
	Concreting	Bennelong	23 - 34	68	62	53
		Kirribilli	24 - 37	64	57	51
		Potts Point	< 20 - 24	61	56	50
	Internal Fitout Works	Bennelong	< 20	68	62	53
		Kirribilli	< 20 - 29	64	57	51
		Potts Point	< 20	61	56	50
	Waste Handling	Bennelong	< 20	68	62	53
		Kirribilli	< 20	64	57	51
		Potts Point	< 20	61	56	50

Table 11 Construction Noise Screening Calculations, Sydney Opera House, Western Sources (occasional deliveries), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level, dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Western Broadwalk	Deliveries	Bennelong	50-51	68	62	53
		Kirribilli	26-31	64	57	51
		Potts Point	< 20	61	56	50

As most of the work is internal and external work at night will be limited to very occasional and unavoidable deliveries, the construction noise levels are not expected to be excessive and would be below the appropriate Noise Affected Levels for nighttime.

Notwithstanding this, proposals are made below (section 7.5) to limit noise levels as far as is reasonably practicable.

7.4.1 Maximum Noise Levels

The predicted maximum noise level from construction activities are presented in Table 12 and assessed against the criteria listed in Section 5.4.1

Table 12 Predicted maximum noise level from construction activities, dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level, dB $L_{A1,1min}$	Sleep disturbance criteria, 10pm - 7am, , $L_{A1,1min}$, dB(A)
Creative Learning Centre, Concert Hall	Internal Demolition	Bennelong	57	63
		Kirribilli	45	61
		Potts Point	33	60
	Concreting	Bennelong	37	63
		Kirribilli	41	61
		Potts Point	28	60
	Internal Fitout Works	Bennelong	32	63
		Kirribilli	46	61
		Potts Point	26	60
	Waste Handling	Bennelong	< 20	63
		Kirribilli	< 20	61
		Potts Point	< 20	60
Western Broadwalk	Deliveries	Bennelong	62	63
		Kirribilli	43	61
		Potts Point	24	60

7.5 Noise Mitigation

7.5.1 Universal Work Practices

The following noise mitigation work practices are recommended to be adopted at all times on site:

- Regularly train workers and contractors (such as at toolbox talks) to use equipment in ways to minimise noise
- Ensure site managers periodically check the site and nearby residences for noise problems so that solutions can be quickly applied
- Probibit the use of radios or stereos outdoors
- Avoid the overuse of public address systems
- Avoid shouting, and minimise talking loudly and slamming vehicle doors, especially during night time works
- Use non-“beeper” reversing/movement alarms such as broadband (non-tonal) alarms or ambient noise-sensing alarms
- Turn off all vehicles, plant and equipment when not in use
- Use residential-grade mufflers on plant
- Ensure all doors/hatches are shut

- Conduct work behind temporary hoardings/screens wherever possible. Site hoardings should be located as close to the noise source as possible, and should be as high as feasible considering the structural support of the hoarding. Site hoardings may not be effective at screening noise to upper floors of sensitive receivers, but can be an effective noise mitigation measure for receivers located on lower floors.

In addition, specific recommended working practices for individual activities are as follows:

7.5.2 Demolition

- Provide resilient damping material on bin trucks or receptacles to minimise impact noise from materials loaded on truck
- Avoid metal-to-metal contact on equipment wherever possible
- Fit mufflers/silencers to pneumatic tools (e.g. breakers)
- Use dampened bits on impulsive tools such as jackhammers to avoid “ringing” noise
- Avoid dropping materials from height
- Use of concrete pulverisers or “munchers” as a lower-noise alternative to concrete breakers

7.5.3 Concert Hall Access

- Provide a solid timber or steel door to close off the temporary opening in the façade for access to the Concert Hall.
- Provide door with gasket seals around the perimeter and a mechanism to hold the door closed
- Ensure that the door is kept closed except when needing to be open for access for plant and materials.

8 Recommendations

On the basis of the above analysis, it is concluded that the proposed development of the Creative Learning Centre and Concert Hall with modifications to the SOH described in this document would not have a detrimental impact on the nearest noise sensitive receivers. However, to minimise potential for noise nuisance, the following recommendations are made.

8.1 Construction Noise

The Sydney Opera House (SOH) has recognised noise issues affecting nearby neighbours during external construction works in the past. Therefore, the Sydney Opera House intends that contractors who are undertaking noisy external works identify mitigation measures for this work in their Construction Noise Management Plan (CNMP) which they will be required to prepare before work starts on site. This CNMP will be reviewed by the SOH and their noise consultants prior to approval and implementation on site.

The Contract with the Managing Contractor will include a clause allowing SOH to disallow any equipment that it considers to be excessively noisy. Similarly, the Managing Contractor may include incentives, as it sees fit, for sub-contractors who can provide noise mitigation measures as part of their contract works.

Should complaints be received, attended acoustic monitoring will be undertaken to ascertain the 'noisier' work activities and address specific work practices and locations to better alleviate noise complaints from that particular activity. A noise logger will also be installed if complaints are received.

Following identification that all noise levels have returned to being consistently below the above maximum levels the monitoring will revert to remote monitoring.

To summarise:

- The recommendations regarding noise mitigation given in Section 7.5 above be implemented.
- Limiting external works at night to only those that are required because of the delivery of items that cannot be accommodated at other times.
- The eventual Contractor be required to prepare a Construction Noise Management Plan.

8.2 Operational Noise

8.2.1 Creative Learning Centre

The activities within the Creative Learning Centre will take place internally in a fully air conditioned space and are not expected to impact on the external environment.

No specific restrictions are considered necessary as it is not expected that any loud activities would take place with the doors open or that events would be sufficiently loud to cause any disturbance to the noise sensitive receivers.

8.2.2 Concert Hall

The proposed changes to the envelope of the concert hall are limited and are not expected to result in any change in noise breakout from events.

Noise from the plant is not expected to be a significant issue affecting residential receivers. Low noise plant has been selected to safeguard the noise-sensitive internal spaces and also to protect the amenity of the public spaces around the Opera House. Calculations show that plant noise will be well below the limits relevant noise limits from the INP.

The treatments to control noise intrusion into the Concert Hall will also ensure that event noise transfer via the ducting to the outside of the venue will not be excessive.

Appendix A

Environmental Noise Surveys

A1.1 Environmental Noise Survey

The noise environment is typical of a busy harbour and inner city. The major noise sources consist of nearby road vehicle traffic and railway noise (i.e. Harbour Bridge) as well as helicopter and ferry noise in Sydney Harbour.

As required by NSW Industrial Noise Policy, an ambient noise survey was conducted in the area from Wednesday, 13 July 2016 to Thursday, 21 July 2016 to determine the existing ambient noise levels at the nearest residential receivers. Additional data was obtained from previous surveys conducted by Arup and Auditoria.

Unattended (noise logging) and attended measurements were conducted to determine representative ambient noise levels in the vicinity of the site during the relevant hours of operation.

A1.2 Methodology

Long term noise monitoring equipment was set up at four locations to log 15 minute measurement intervals of L_{Aeq}, L_{A10} and L_{A90} with a fast (0.125s) time weighting.

Meteorological conditions were monitored during the survey period. The relevant measurement intervals affected by adverse weather and extraneous noise events were removed.

Short term 15 minute attended measurements were undertaken at logger location 3 on Wednesday, 13 July 2016 and Thursday, 21 July 2016 to obtain detailed noise information for weekday daytime activities. Attended Measurements were taken at location 4 on Thursday, 7 March 2013.

A1.3 Measurement Locations

Figure 1 shows the four noise logger locations on a map of the area. Logger locations were chosen taking into account security and access restrictions and are considered representative of the surrounding areas and nearest potentially affected receivers.

Unattended noise monitoring data was provided by Auditoria for locations 1 and 2. Loggers were positioned on level 4 and level 9 at the northern façade of Bennelong Apartments as shown in figure 2 (left).

Noise logger 3 was positioned in front of the southern façade of an apartment building at 29 Waruda Street Kirribilli with line of sight view of the Sydney Opera House as shown in figure 2 (right).

Logger 4 is from a previous noise assessment conducted by Arup from 7 March 2013 to 15 March 2013 at the Juanita Nielsen Centre (JNC) located in Woolloomooloo, Sydney. It is considered representative of the ambient noise in

the nearby suburb of Potts Point. A noise logger was installed on the first floor approximately 1m off the 31 Nicholson Street façade.

Figure 1: Map of logger locations.

Figure 2: Noise monitoring location at Bennelong Apartments (left) and Kirribilli (right).

Figure 3: Noise logger setup, Juanita Nielsen Centre Woolloomooloo.

A1.4 Equipment

The equipment used to measure the baseline noise levels is detailed in Table 1. Equipment used at location 3 and 4 was checked for calibration before and after measurements with no significant drift in calibration being recorded. All equipment used at location 3 and 4 held a current NATA calibration certificate at the time of the survey.

Table 1: Equipment used to conduct noise survey

Type	Model	Serial No.	Location
Noise Logger	ARL Ngara Type 1 Microphone	8780b4	Bennelong level 4
Noise Logger	ARL Ngara Type 1 Microphone	8780f0	Bennelong level 9
Noise Logger	ARL Ngara Type 1 Microphone	8780e8	29 Waruda St Kirribilli
Noise Logger	RTA Technology 04	T229736	JNC Woolloomooloo
Sound Level Meter	Brüel & Kjaer Type 2250	2449851	
Calibrator	Brüel & Kjaer Type 4231	3000079	

A1.5 Short Term Attended Noise Measurement Results

Short term measurements (15 minutes) of environmental noise were carried out at location 3 at the time of commissioning and decommissioning the noise loggers. At location 4, attended measurements were conducted at both the logger (JNC level 1) and at 1.5m above ground at the corner of Nicholson Street and Dowling Street. The attended measurement results a summarized in Table 2.

Table 2: Attended noise survey results

Location	Date	Time	$L_{Aeq, 15min}$	$L_{A90, 15min}$	$L_{A10, 15min}$	$L_{A1, 15min}$
29 Waruda Street Kirribilli	13-Jul-16	15:00	62 dB	59 dB	57 dB	76 dB
	13-Jul-16	09:30	57 dB	55 dB	54 dB	73 dB
1st Floor of JNC	7-March-13	09:40	60 dB	53 dB	63 dB	65 dB

Location	Date	Time	$L_{Aeq, 15min}$	$L_{A90, 15min}$	$L_{A10, 15min}$	$L_{A1, 15min}$
Nicholson Street/ Dowling Street Corner	7-March-13	10:10	56 dB	48 dB	59 dB	65 dB

A1.6 Long Term Unattended Noise Logging Results

Measured noise levels from the unattended noise survey at all four locations is summarised in Table 3. Summary results have been split into standard Day, Evening and Night time periods as defined in the NSW Industrial Noise Policy.

Averaged daily summary graphs of the noise logging are provided in Section A1.7 and individual daily graphs are available upon request.

Table 3: Summary of measure noise indices

Location	Time Period	Rating Background Level (RBL) – dB(A)	$L_{Aeq (period)}$, dB
Location 1 - Level 4, 1e Macquarie Street	Day (7:00 – 18:00)	59	64
	Evening (18:00 – 22:00)	59	62
	Night (22:00 – 7:00)	48	57
Location 2 - Level 9, 1e Macquarie Street	Day (7:00 – 18:00)	58	62
	Evening (18:00 – 22:00)	57	61
	Night (22:00 – 7:00)	49	56
Combined Bennelong data for report*	Day (7:00 – 18:00)	58	62
	Evening (18:00 – 22:00)	57	61
	Night (22:00 – 7:00)	48	56
Location 3 - 29 Waruda Street Kirribilli	Day (7:00 – 18:00)	54	61
	Evening (18:00 – 22:00)	52	57
	Night (22:00 – 7:00)	46	54
Location 4 – JNC, Nicholson Street Woolloomooloo	Day (7:00 – 18:00)	51	63
	Evening (18:00 – 22:00)	51	61
	Night (22:00 – 7:00)	45	56

*Note: The background noise levels from two monitoring locations at Bennelong Apartments were combined for simplicity in the report (Section 4.1 - Table 1). The lowest values were taken for the most stringent criteria.

A1.7 Observations

Ambient noise levels are generally constant between the hours of 8:00 am and 9:00 pm for the receivers located at the Bennelong apartments.

At location 3 the ambient noise levels are generally constant between the hours 5:45 am and 9:30 pm. The rise in short term noise levels from 4:00 pm to 5:00 pm is due to increased helicopter and ferry activity during this period of the day. Attended measurements indicate the main continuous noise source was traffic on the Sydney Harbour Bridge approximately 520m to the west and water slapping the sea wall 8m from the logger. A large ferry caused peak levels of 65 dB(A) and a helicopter approximately 200m away caused a peak level of 76 dB(A). An additional measurement taken whilst decommissioning the logger confirmed the main noise sources as traffic on the Harbour Bridge and Ferries. It was noted that bird life contributed to the peak noise levels from 69-73 dB(A).

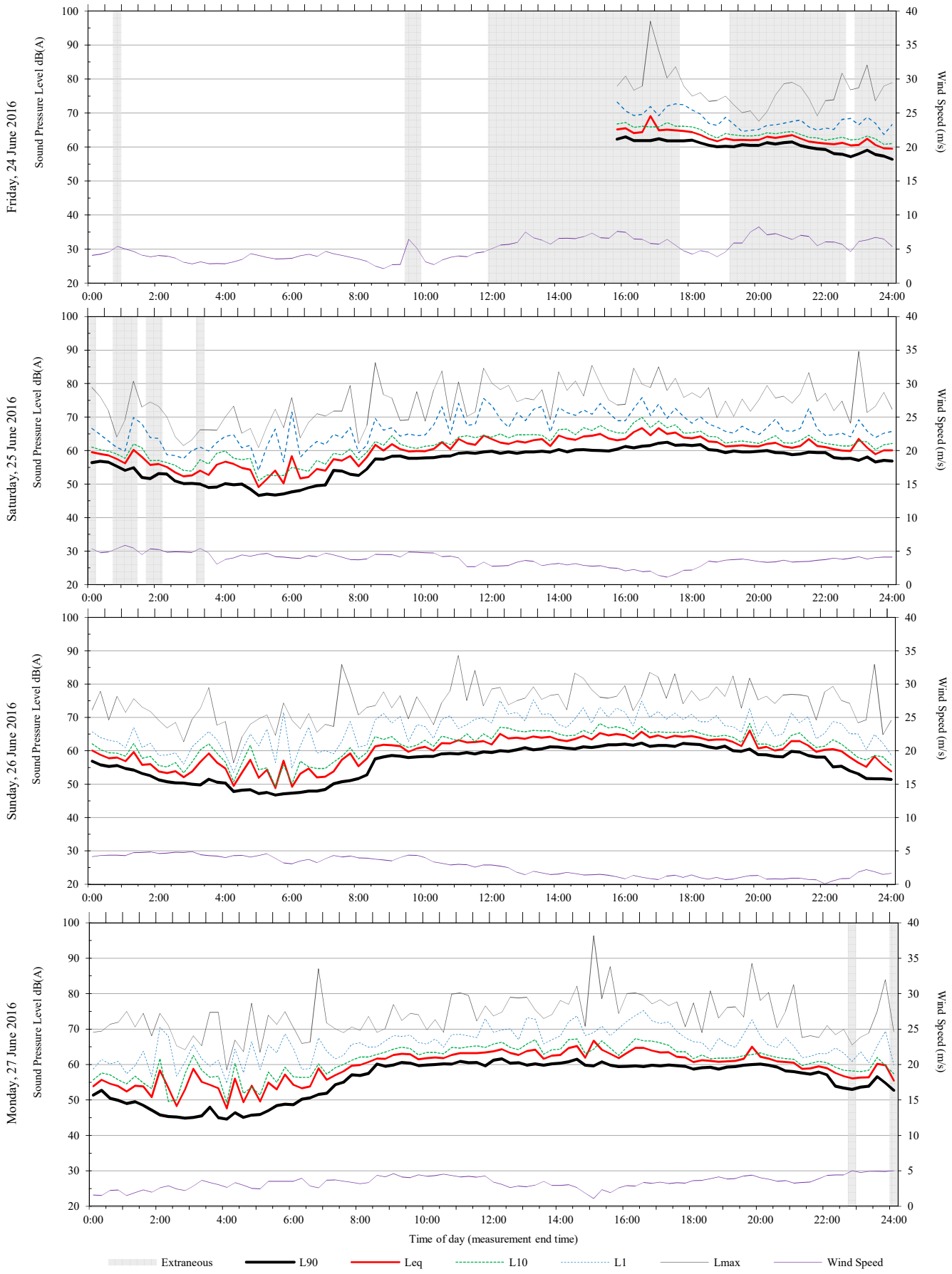
At location 4 the L_{Aeq} noise levels are generally constant from 6:00 am to 8:00 pm however the background noise levels generally increased as the day progressed, reaching the highest value in the evening. This is likely due to the increase in pedestrian activity in the vicinity from the Woolloomooloo entertainment precinct.

A1.8 Survey Data

A1.8.1 Location 1 – Bennelong Apartments level 4

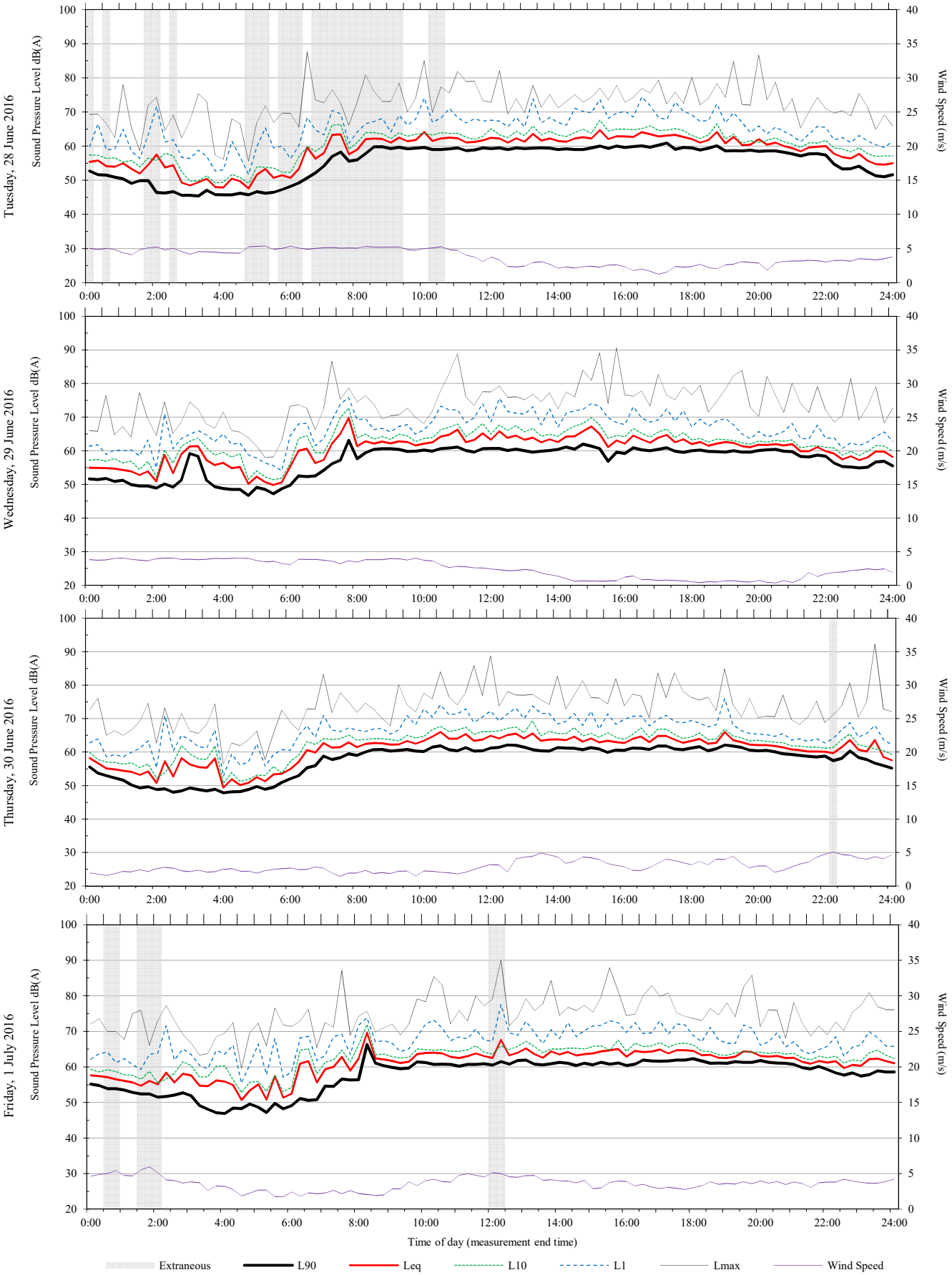
Unattended monitoring: Bennelong Apartments - Level 4

ARUP



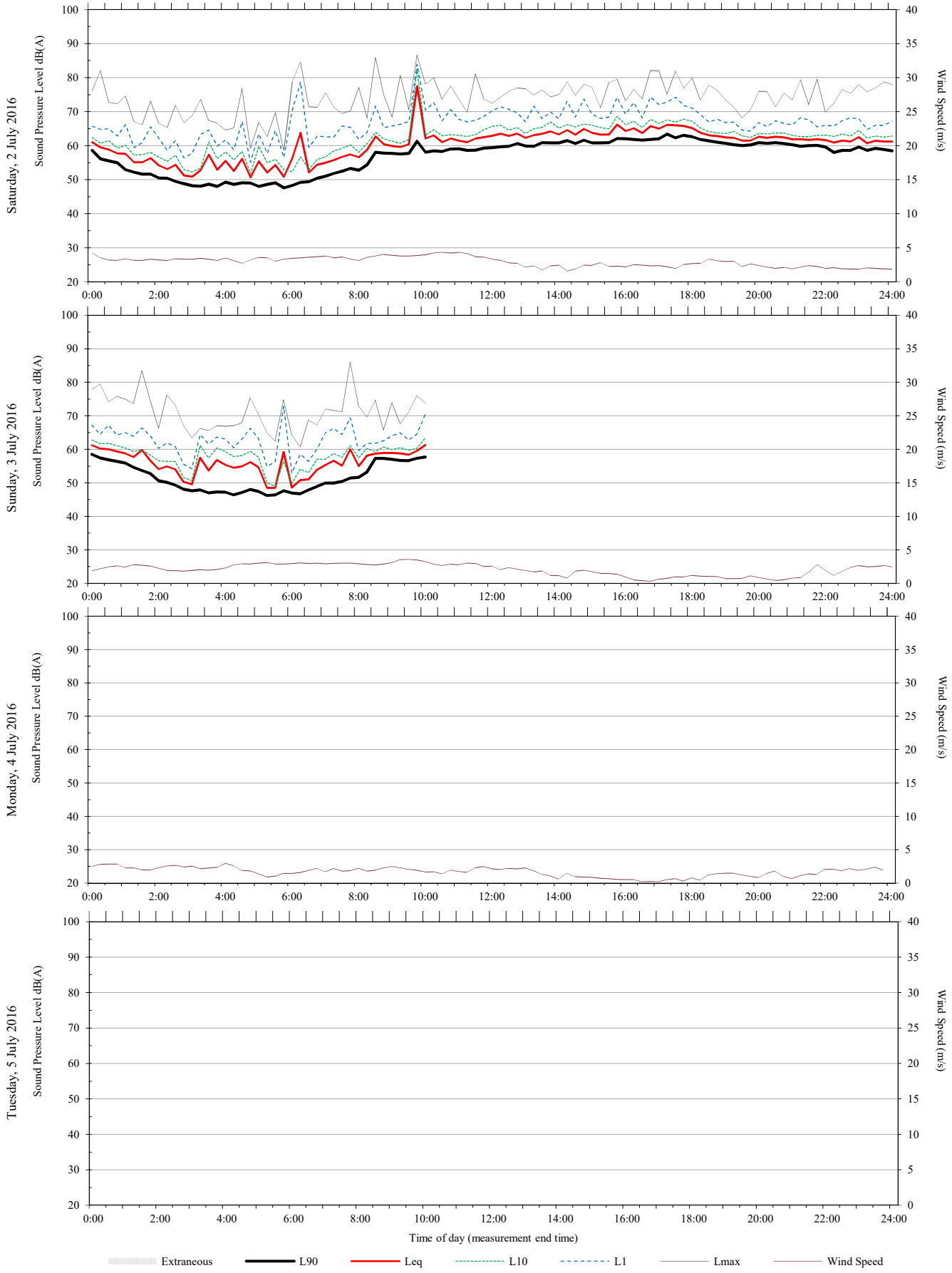
Unattended monitoring: Bennelong Apartments - Level 4

ARUP



Unattended monitoring: Bennelong Apartments - Level 4

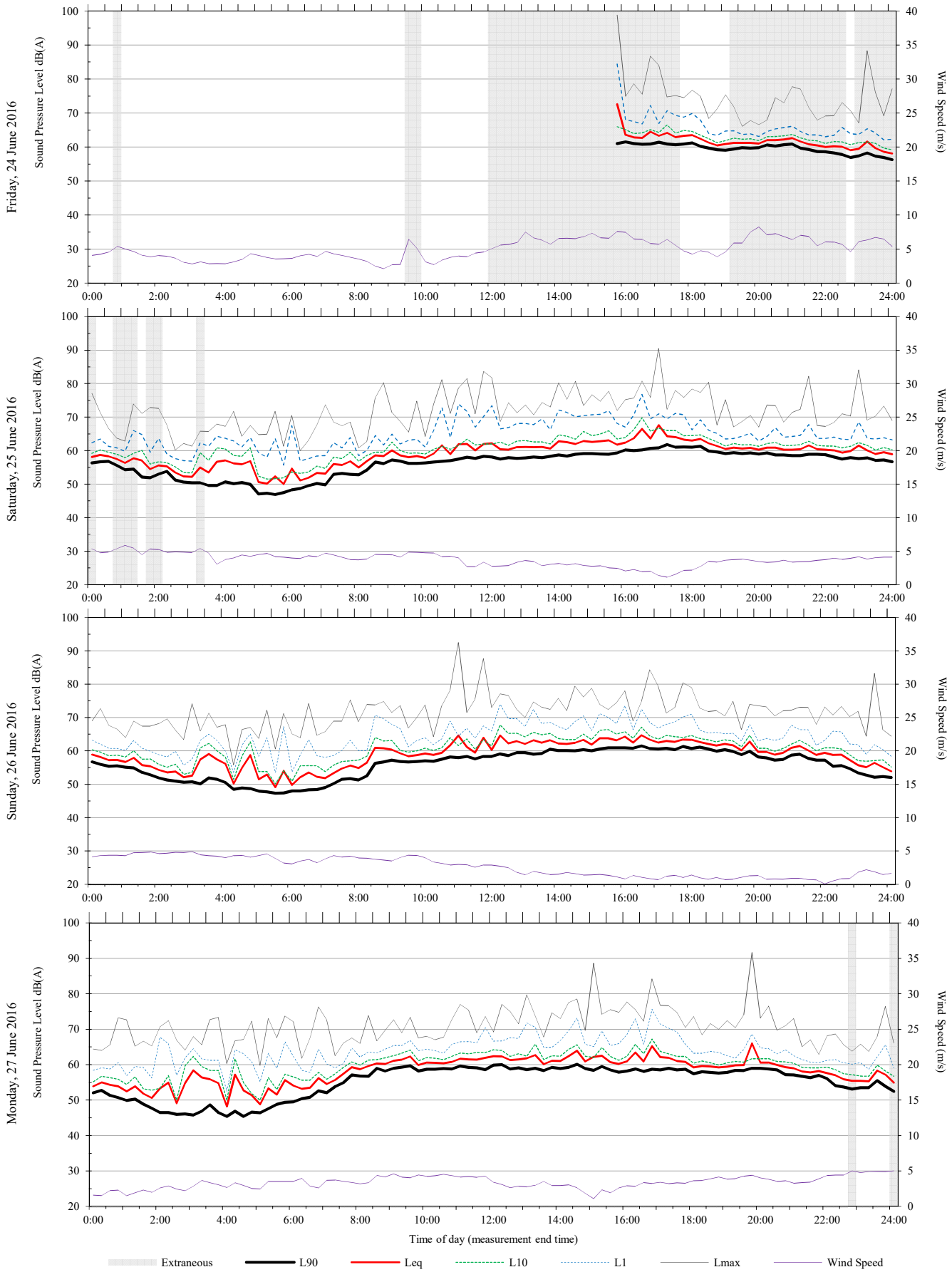
ARUP



A1.8.2 Location 2 - Bennelong Apartments Level 9

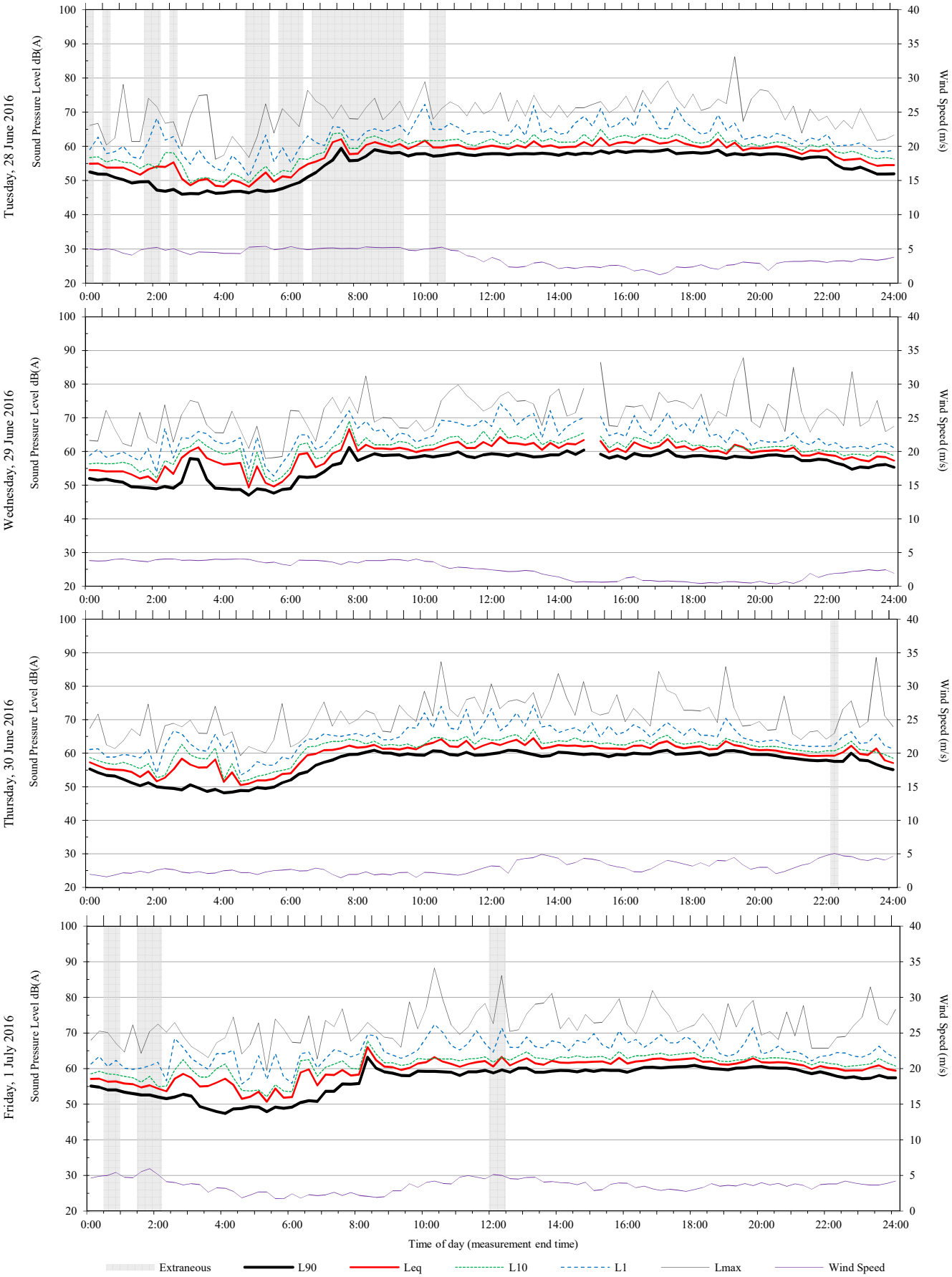
Unattended monitoring: Bennelong Apartments - Level 9

ARUP



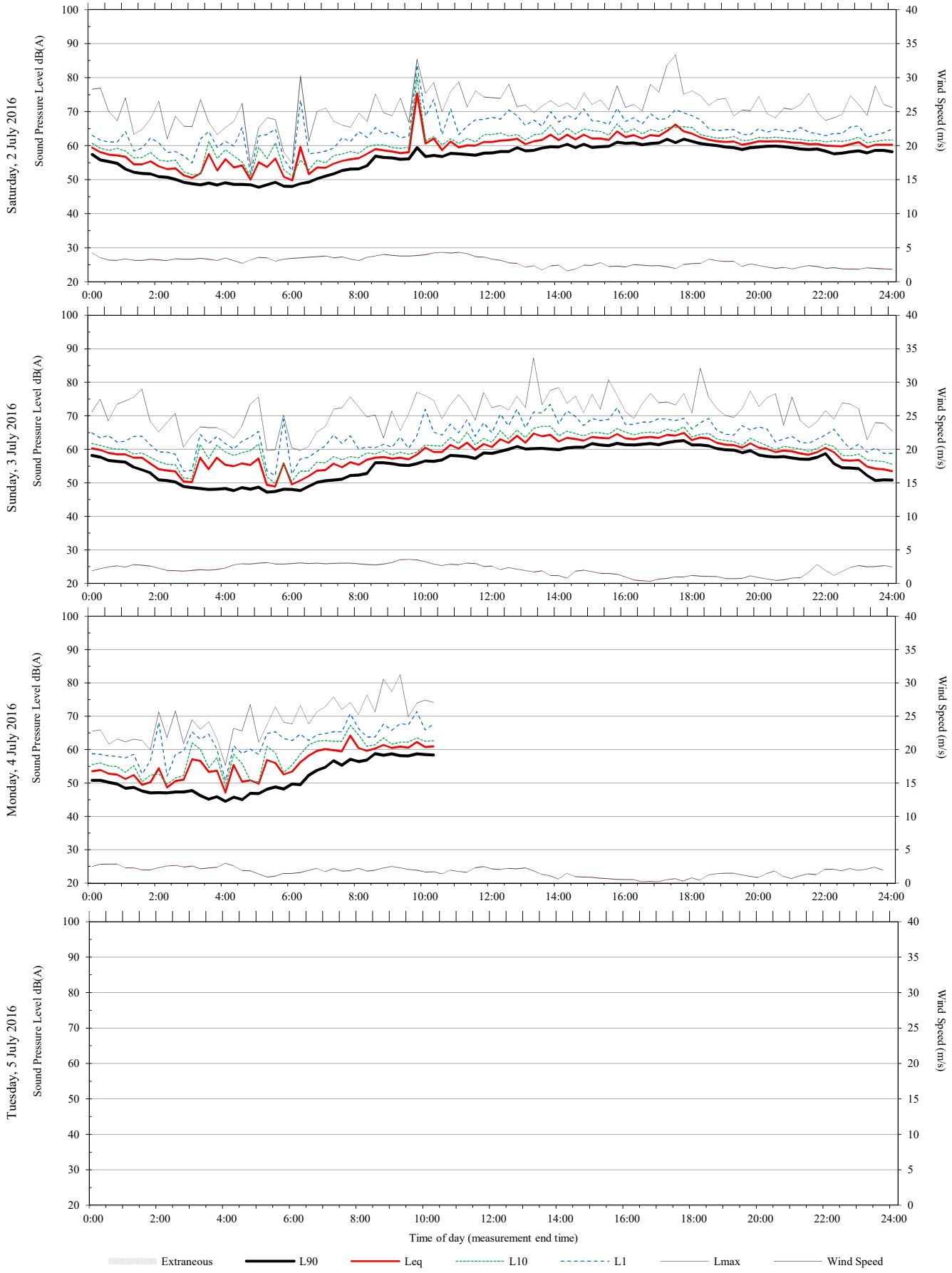
Unattended monitoring: Bennelong Apartments - Level 9

ARUP



Unattended monitoring: Bennelong Apartments - Level 9

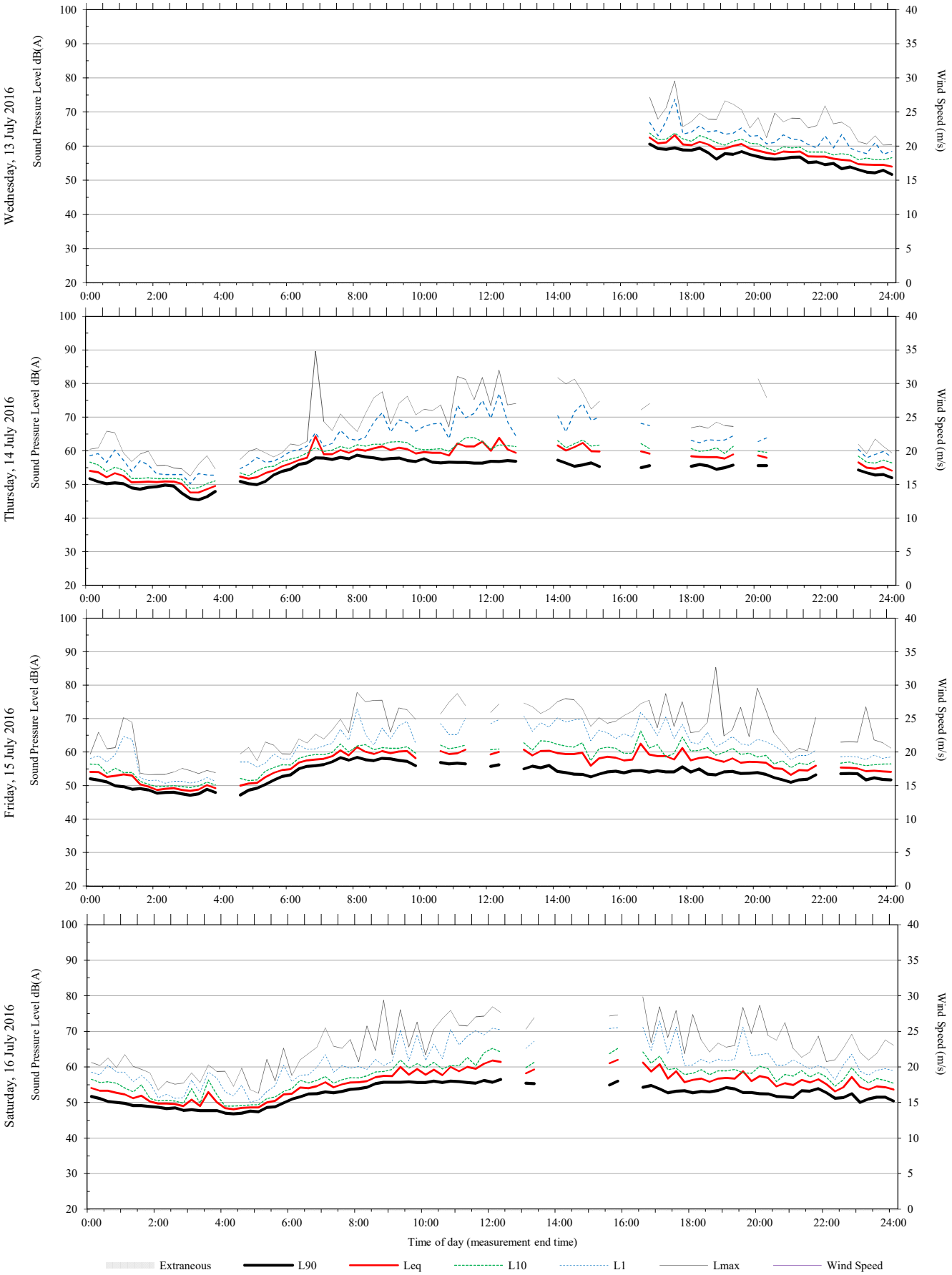
ARUP



A1.8.3 Location 3 – 29 Waruda Street Kirribilli

Unattended monitoring: Kirribilli (Free Field)

ARUP



Unattended monitoring: Kirribilli (Free Field)

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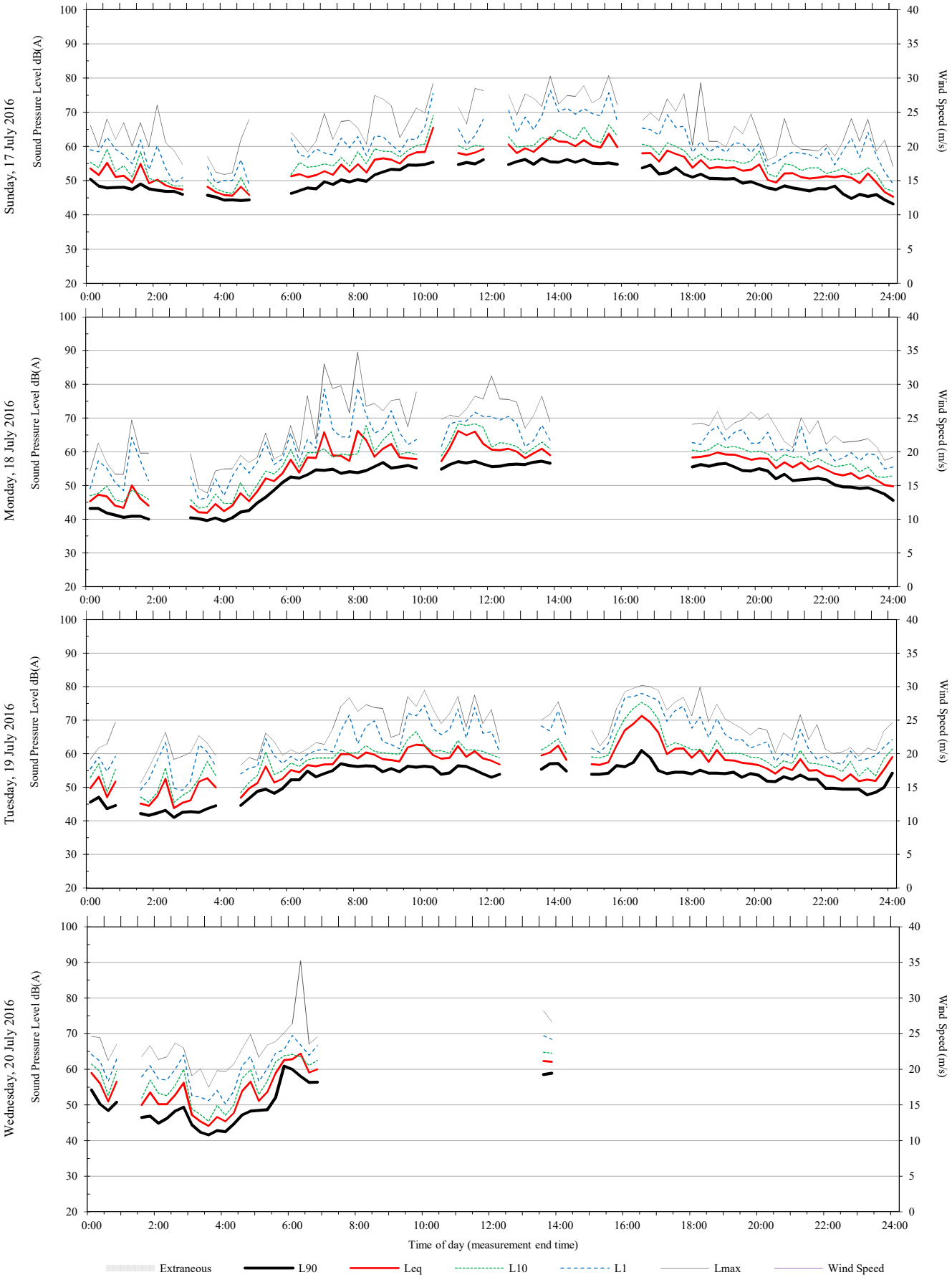

Unattended monitoring: Kirribilli (Free Field)

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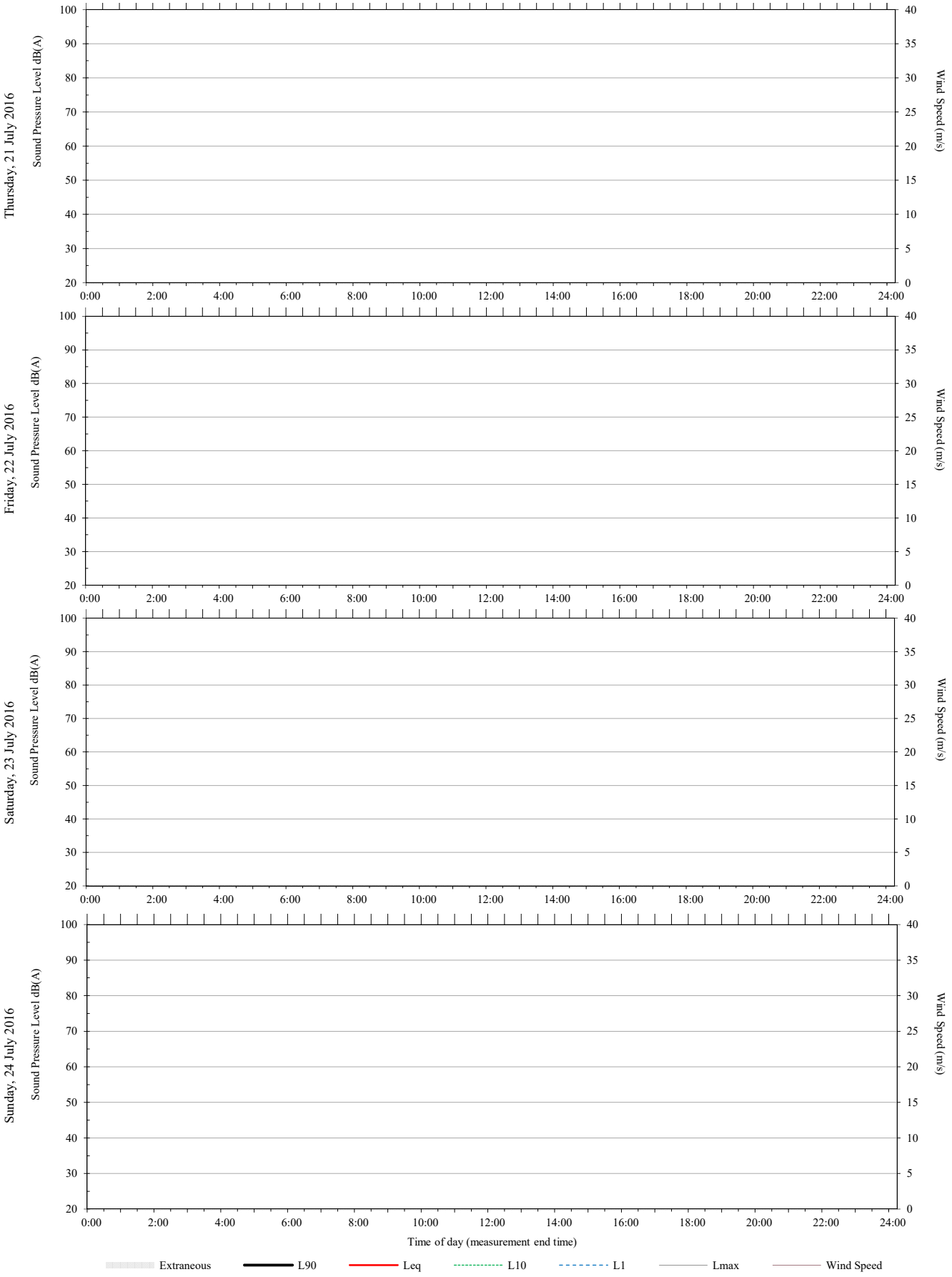
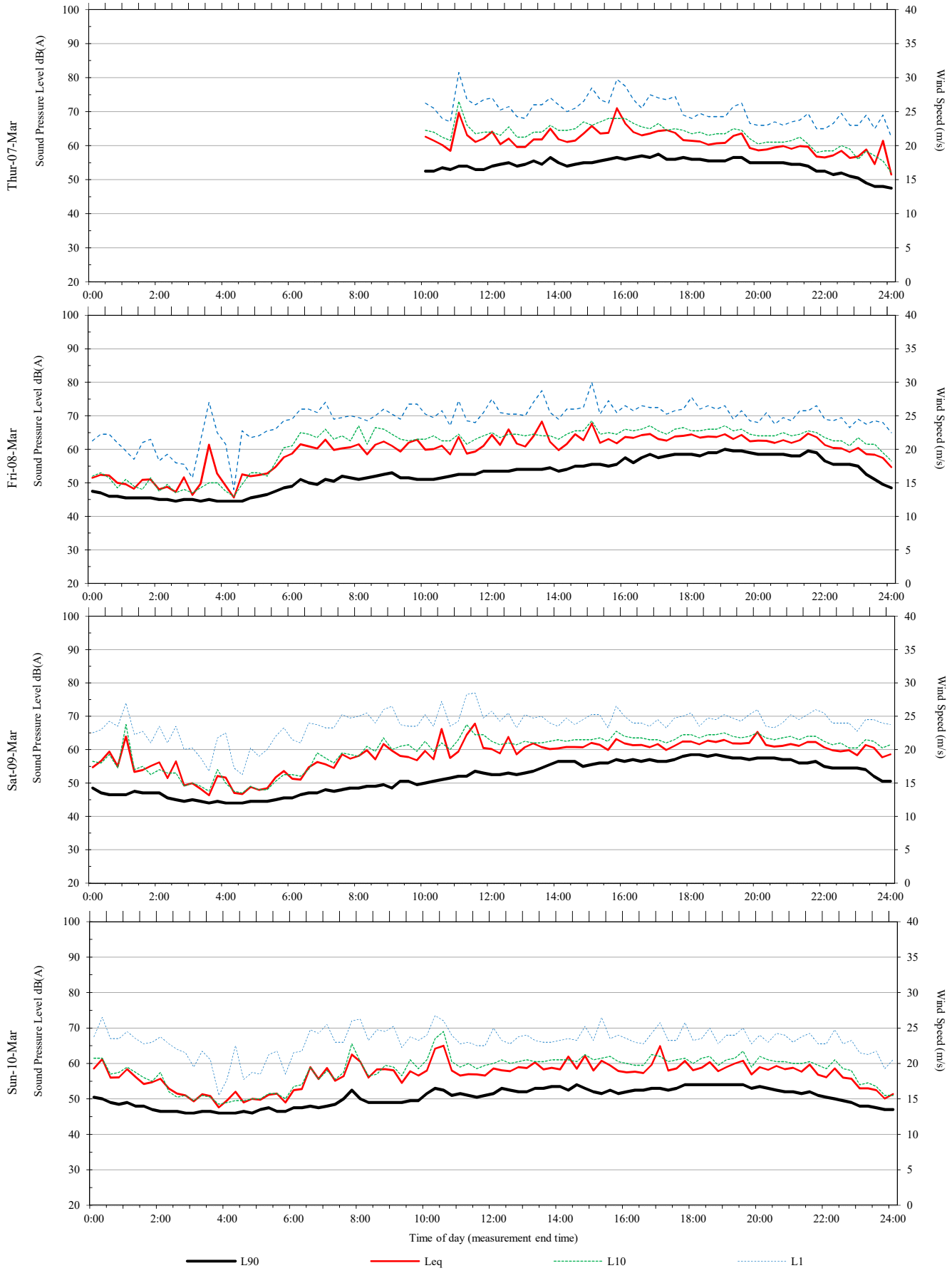


A1.8.4 Location 4 – JNC Nicholson Street Woolloomooloo

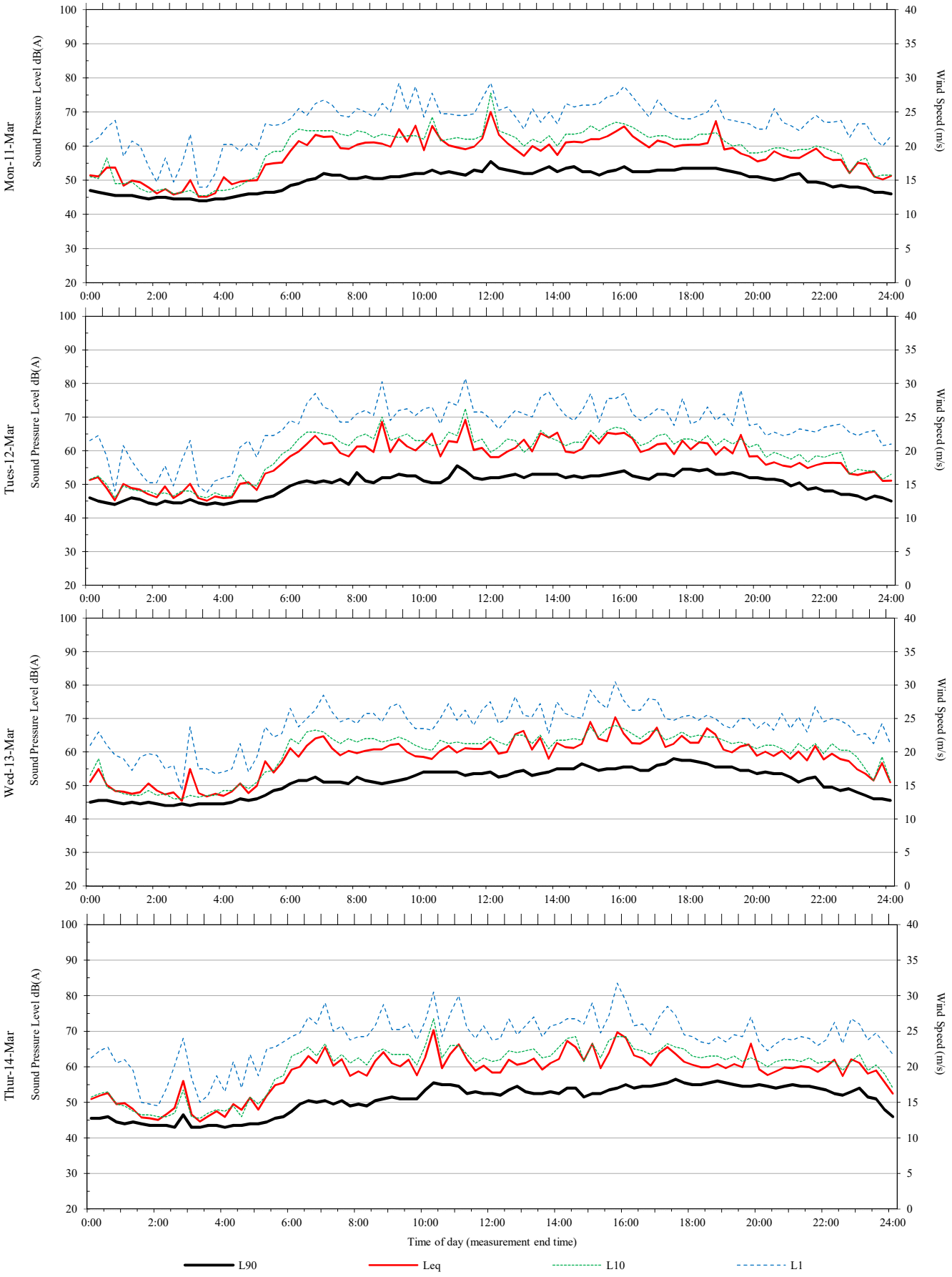
Unattended monitoring: Juanita Nielsen Community Centre (Free Field)

ARUP



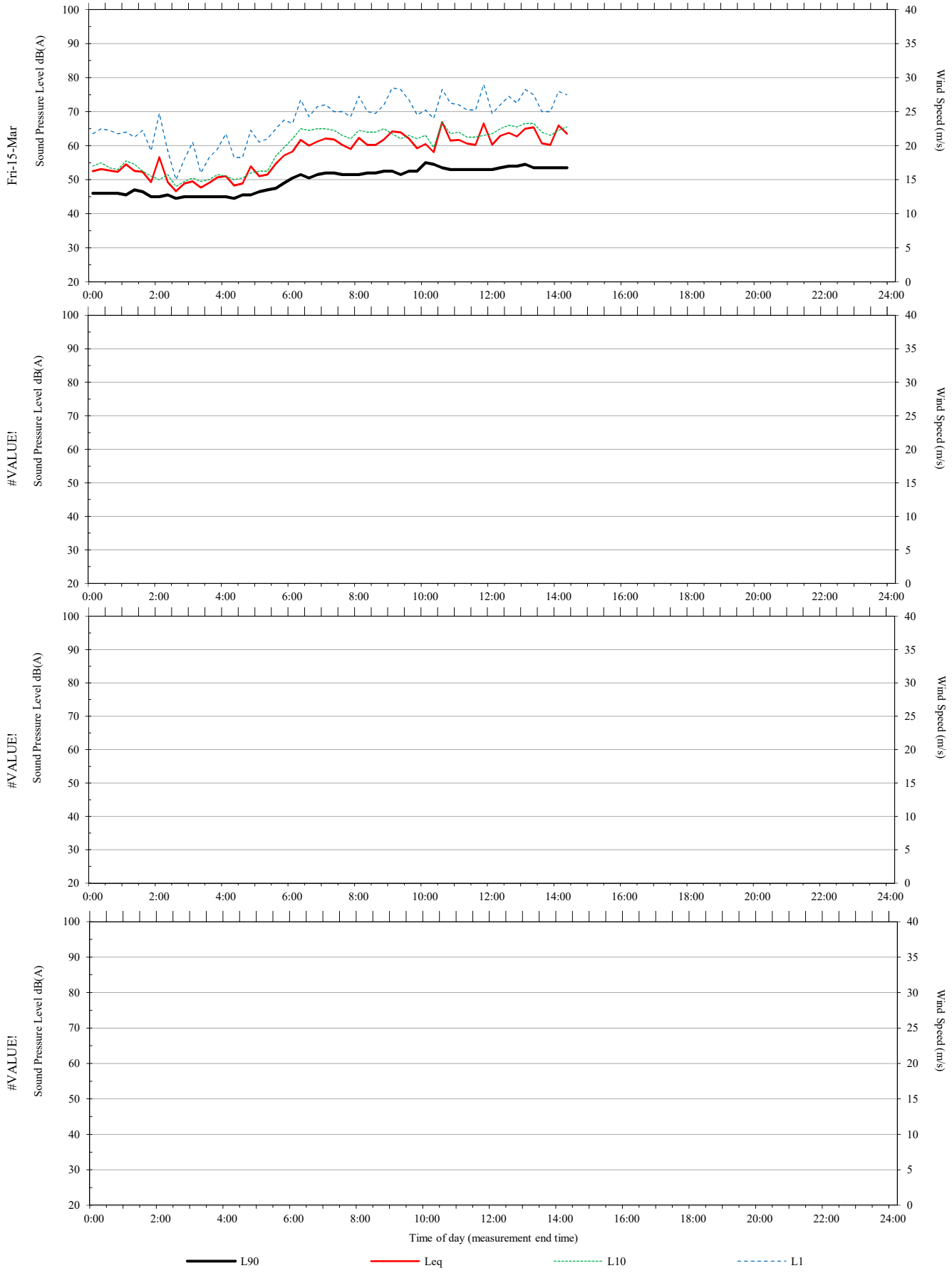
Unattended monitoring: Juanita Nielsen Community Centre (Free Field)

ARUP



Unattended monitoring: Juanita Nielsen Community Centre (Free Field)

ARUP



Appendix B

Acoustic Glossary

Ambient Noise Level

The ambient noise level is the overall noise level measured at a location from multiple noise sources. When assessing noise from a particular development, the ambient noise level is defined as the remaining noise level in the absence of the specific noise source being investigated. For example, if a fan located on a city building is being investigated, the ambient noise level is the noise level from all other sources without the fan running. This would include sources such as traffic, birds, people talking and other nearby fans on other buildings.

Background Noise Level

The background noise level is the noise level that is generally present at a location at all or most times. Although the background noise may change over the course of a day, over shorter time periods (e.g. 15 minutes) the background noise is almost-constant. Examples of background noise sources include steady traffic (e.g. motorways or arterial roads), constant mechanical or electrical plant and some natural noise sources such as wind, foliage, water and insects.

Assessment Background Level (ABL)

A single-number figure used to characterise the background noise levels from a single day of a noise survey. ABL is derived from the measured noise levels for the day, evening or night time period of a single day of background measurements. The ABL is calculated to be the tenth percentile of the background L_{A90} noise levels – i.e. the measured background noise is above the ABL 90% of the time.

Rating Background Level (RBL)

A single-number figure used to characterise the background noise levels from a complete noise survey. The RBL for a day, evening or night time period for the overall survey is calculated from the individual Assessment Background Levels (ABL) for each day of the measurement period, and is numerically equal to the median (middle value) of the ABL values for the days in the noise survey.

Decibel

The decibel scale is a logarithmic scale which is used to measure sound and vibration levels. Human hearing is not linear and involves hearing over a large range of sound pressure levels, which would be unwieldy if presented on a linear scale. Therefore a logarithmic scale, the decibel (dB) scale, is used to describe sound levels (dB SPL ref 20µPa).

An increase of approximately 10 dB corresponds to a subjective doubling of the loudness of a noise. The minimum increase or decrease in noise level that can be noticed is typically 2 to 3 dB.

dB(A)

dB(A) denotes a single-number sound pressure level that includes a frequency weighting ("A-weighting") to reflect the subjective loudness of the sound level.

The frequency of a sound affects its perceived loudness. Human hearing is less sensitive at low and very high frequencies, and so the A-weighting is used to account for this effect. An A-weighted decibel level is written as dB(A).

Some typical dB(A) levels are shown below.

Noise Level dB(A)	Example
130	Human threshold of pain
120	Jet aircraft take-off at 100 m
110	Chain saw at 1 m
100	Inside nightclub
90	Heavy trucks at 5 m
80	Kerbside of busy street
70	Loud stereo in living room
60	Office or restaurant with people present
50	Domestic fan heater at 1m
40	Living room (without TV, stereo, etc)
30	Background noise in a theatre
20	Remote rural area on still night
10	Acoustic laboratory test chamber
0	Threshold of hearing

L_{10}

The L_{10} statistical level is often used as the "average maximum" level of a sound level that varies with time.

Mathematically, the L_{10} level is the sound level exceeded for 10% of the measurement duration. L_{10} is often used for road traffic noise assessment. As an example, 63 dB $L_{A10,18hr}$ is a sound level of 63 dB(A) or higher for 10% of the 18 hour measurement period.

L_{90}

The L_{90} statistical level is often used as the "average minimum" or "background" level of a sound level that varies with time.

Mathematically, L_{90} is the sound level exceeded for 90% of the measurement duration. As an example, 45 dB $L_{A90,15min}$ is a sound level of 45 dB(A) or higher for 90% of the 15 minute measurement period.

L_{eq}

The 'equivalent continuous sound level', L_{eq}, is used to describe the level of a time-varying sound or vibration measurement.

L_{eq} is often used as the "average" level for a measurement where the level is fluctuating over time. Mathematically, it is the energy-average level over a period of time (i.e. the constant sound level that contains the same sound energy as the measured level). When the dB(A) weighting is applied, the level is denoted dB L_{Aeq}. Often the measurement duration is quoted, thus $L_{Aeq,15\ min}$ represents the dB(A) weighted energy-average level of a 15 minute measurement.

L_{max}

The L_{max} statistical level can be used to describe the "absolute maximum" level of a sound or vibration level that varies with time.

Mathematically, L_{max} is the highest value recorded during the measurement period. As an example, 94 dB L_{Amax} is a highest value of 94 dB(A) during the measurement period.

Since L_{max} is often caused by an instantaneous event, L_{max} levels often vary significantly between measurements.

Frequency

Frequency is the number of cycles per second of a sound or vibration wave. In musical terms, frequency is described as "pitch". Sounds towards the lower end of the human hearing frequency range are perceived as "bass" or "low-pitched" and sounds with a higher frequency are perceived as "treble" or "high pitched".

Sound Power and Sound Pressure

The sound power level (Lw) of a source is a measure of the total acoustic power radiated by a source. The sound pressure level (Lp) varies as a function of distance from a source. However, the sound power level is an intrinsic characteristic of a source (analogous to its mass), which is not affected by the environment within which the source is located.